- establish a support centre for STI using a common methodological approach to ensure unified legislative frameworks and the development of standard tools to assess STI policy implementation;
- provide one another with foreign direct investment, in order to diversify sources of R&D funding and foster intraregional co-operation in areas of common interest, including renewable energy, biotechnology, biodiversity conservation and medicine;
- develop more infrastructure to foster innovation: science and technology parks, special industrial zones, business incubators for start-ups and spin-offs, etc.; and
- co-operate in training highly qualified specialists for the knowledge economy: managers and engineers for innovative projects; intellectual property lawyers, including as concerns international law, patent marketers and so on.

KEY TARGETS FOR CENTRAL ASIA

- Raise Kazahkstan's GERD/GDP ratio to 1% by 2015;
- Raise the share of innovative activity in Kazakh enterprises to 10% by 2015 and 20% by 2020;
- Carry the weight of the Kazakh manufacturing sector to 12.5% of GDP by 2020;
- Reduce the share of the Kazakh population living below the poverty line to 8% by 2020;
- Cultivate 15% of the acreage in Kazakhstan with water-saving technologies and develop drought-resistant genetically modified crops by 2030;
- Place Kyrgyzstan among the top 30 countries for doing business by 2017 and the 50 least corrupt by 2017;
- Ensure that all Kyrgyz faculty members hold at least a master's degree and 10% a PhD or Doctor of Science degree by 2020;
- Privatize 30% of Tajik pre-schools, vocational schools and universities by 2015;
- Equip 50% of Tajik schools with internet access by 2015;
- Ensure that 50% of Tajik scientific projects are in applied fields by 2015.

REFERENCES

Amanniyazova, L. (2014) Social transfers and active incomes of population. *Golden Age* (online newspaper), 1 February. See: http://turkmenistan.gov.tm

CCSTD (2013) *Social Development and Standards of Living in Uzbekistan*. Statistical Collection. Committee for Co-ordination of Science and Technology Development. Government of Uzbekistan: Tashkent.

Government of Kazakhstan (2010) *State Programme for Accelerated Industrial and Innovative Development*. Approved by presidential decree no. 958, 19 March. See: www.akorda.kz/en/category/gos_programmi_razvitiya

Oilnews (2014) Kazakhstan creates investment fund for projects in the field of renewable energy sources. *Oilnews*. See: http://oilnews.kz/en/home/news

Ospanova, R. (2014) Nazarbayev University to host International Science and Technology Centre. *Astana Times*, 9 June.

President of Kazakhstan (2014) *The Kazakhstan Way – 2050: One Goal, One Interest and One Future*. State of the Nation Address by President Nursultan Nazarbayev. See: www.kazakhembus.com

Satke, R. (2014) Russia tightens hold on Kyrgyzstan. *Nikkei Asia Review*, 27 March.

Sharman, A. (2012) Modernization and growth in Kazakhstan. *Central Asian Journal of Global Health*, 1 (1).

Spechler, M. C. (2008) The Economies of Central Asia: a Survey. *Comparative Economic Studies,* 50: 30–52.

Stark, M. and J. Ahrens (2012) *Economic Reform and Institutional Change in Central Asia: towards a New Model of the Developmental State?* Research Papers 2012/05. Private Hochschule: Göttingen.

UNECE (2012) *Innovation Performance Review: Kazakhstan*. United Nations Economic Commission for Europe: New York and Geneva.

Uzstat (2012) *Statistical Yearbook*. Uzbek Statistical Office: Tashkent.

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Indirectly, international sanctions have had some benefits for science, technology and innovation in Iran.

Kioomars Ashtarian

Professor Maryam Mirzakhani speaking at the International Congress of Mathematicians in Seoul (Republic of Korea) in 2014, where she was awarded the Field's Medal, the Nobel equivalent for mathematics

Photo: © International Mathematical Union

15 · Iran

Kioomars Ashtarian

INTRODUCTION

Sanctions have reshaped public policy in Iran

In the *UNESCO Science Report 2010,* we discussed how high oil receipts had stimulated consumerism but divorced science from socio-economic needs, favouring a science push rather than a technology pull. In more recent years, Iran has been less able to rely on oil receipts, as the embargo has tightened its grip: oil exports shrank by 42% between 2010 and 2012, dropping from 79% to 68% of total exports.

This predicament has reshaped Iranian public policy. The transition from a resource-based economy to a knowledge economy was already programmed in the *Vision 2025* document adopted in 2005. However, it has taken the hardening of sanctions – and a change of government – for policy-makers to make this transition a priority.

Four of the resolutions adopted by the United Nations Security Council since 2006 include progressively tough sanctions. Since 2012, the USA and European Union (EU) have imposed additional restrictions on Iranian oil exports and on enterprises and banks accused of circumventing the sanctions. The embargo is designed to persuade Iran to stop enriching uranium, which can be used for both civilian and military purposes.

Iran has always insisted on the civil nature of its nuclear programme[1] and its compliance with the Nuclear Non-Proliferation Treaty. Civil nuclear science is a source of national pride, in much the same way that Iranians are proud of their prowess in nanotechnology, stem cell technology and satellite technology. There was extensive coverage in the national press when Maryam Mirzakhani (*see photo*) became the first woman and the first Iranian in 2014 to be awarded the Fields Medal, the Nobel equivalent for mathematics.

President Hassan Rouhani took office in 2013 with the intention of dialoguing with the West. He rapidly initiated a new round of negotiations with the contact group, made up of the five permanent members of the United Nations Security Council plus Germany (known as the P5+1). The first concrete sign of a drop in tensions came in November 2013 with the conclusion of an interim arrangement with the P5+1. Shortly thereafter, the EU General Court announced that it would be annulling sanctions against the Central Bank of Iran. Another interim agreement in mid-2014 has allowed oil exports to climb back gradually to 1.65 million barrels per day. A final agreement was signed on 14 July 2015 and rapidly endorsed by the United Nations Security Council, paving the way to the lifting of sanctions.

1. Iran currently has a single nuclear reactor, located in Bouchehr.

Iran trades with the East …

Between 2010 and 2012, non-oil exports rose by 12%, as Iran sought to cushion the economic impact of sanctions by limiting cash sales. Iran was able to import gold, for instance, in exchange for exporting goods to other countries. China is one of Iran's biggest customers but owes an estimated US$ 22 billion for oil and gas supplies which cannot be paid due to banking sanctions. In late 2014, China was planning to invest an equivalent sum in electricity and water projects as a way of circumventing the restrictions.

Like China, the Russian Federation is one of Iran's main trading partners.In October 2014, the Iranian agriculture minister met with his Russian counterpart on the sidelines of a Shanghai Cooperation Organization meeting in Moscow to discuss a new trade deal, whereby Iran would export vegetables, protein and horticultural products to the Russian Federation, in exchange for imports of some engineering and technical services, cooking oil and grain products. In September 2014, the Iranian Mehr news agency reported that Iran had signed a US$ 10 billion agreement with Russia for the design and construction of four new thermal[2] power plants, as well as facilities for the transfer of electricity.

The sanctions have caused a distinct shift in Iran's trading partners from West to East. Since 2001, China's exports to Iran have increased almost sixfold. The EU, on the other hand, accounted for almost 50% of Iranian trade in 1990 but, today, represents just 21% of Iranian imports and less than 5% of its exports.

… but conducts science with East and West

Scientific collaboration, on the other hand, has remained largely oriented towards the West. Between 2008 and 2014, the top four partners for scientific co-authorship were, in descending order, the USA, Canada, the UK and Germany (Figure 15.1). In 2012, researchers from Iran began participating in the project to build an International Thermonuclear Experimental Reactor[3] in France by 2018, which is developing nuclear fusion technology. In parallel, Iran is stepping up its collaboration with developing countries. Malaysia is Iran's fifth-closest collaborator in science and India ranks tenth, after Australia, France, Italy and Japan.

This said, just one-quarter of Iranian articles have a foreign co-author. There is a lot of scope for the development of twinning between universities for teaching and research, as well as student exchanges (Hariri and Riahi, 2014). Ties with Malaysia

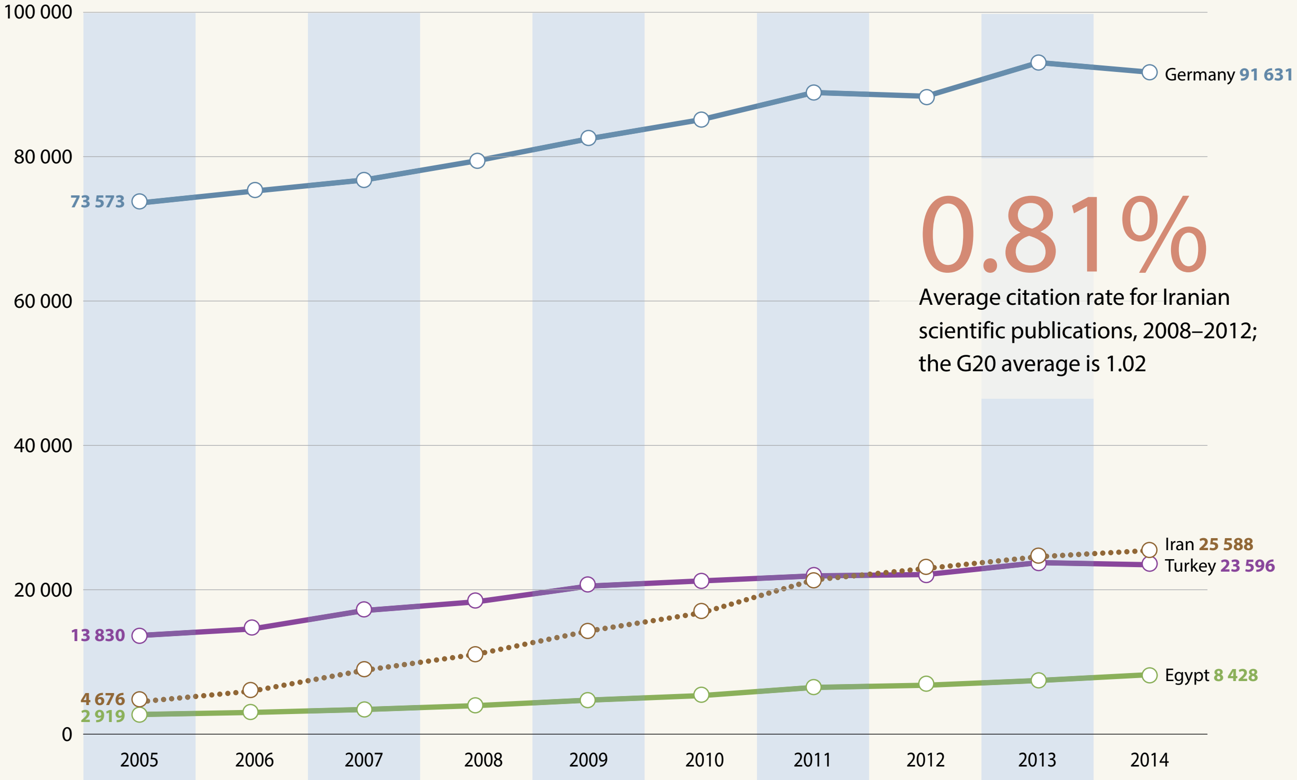
2. There are different types of thermal power plant: nuclear, geothermal, coal-driven, biomass-burning, etc.

3. This project is funded by the European Union (*circa* 45% of the budget), China, India, Japan, the Republic of Korea and the USA.

Figure 15.1: **Scientific publication trends in Iran, 2005–2014**

Strong growth in Iranian publications

Countries with a similar population are given for comparison



7.4%

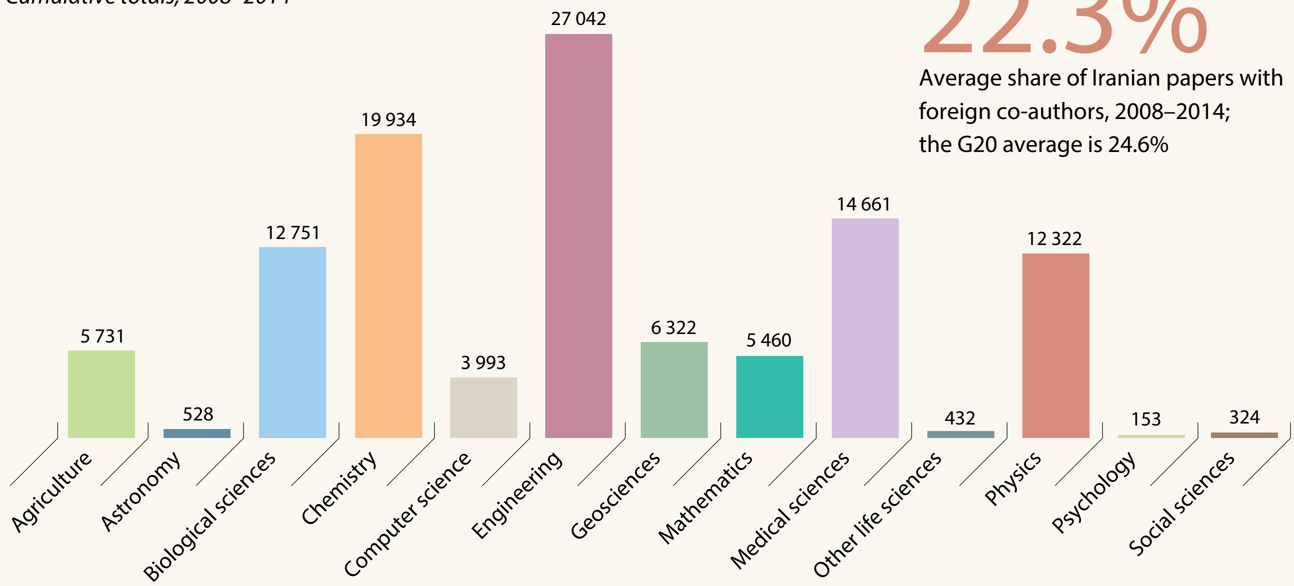
Average share of Iranian papers among 10% most cited papers, 2008–2012; the G20 average is 10.2%

0.81%

Average citation rate for Iranian scientific publications, 2008–2012; the G20 average is 1.02

Iranians now publish most in engineering, followed by chemistry

Cumulative totals, 2008–2014



Note: Totals exclude unclassified articles

22.3%

Average share of Iranian papers with foreign co-authors, 2008–2014; the G20 average is 24.6%

The USA is Iran's top collaborator

Main foreign partners between 2008 and 2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Iran	USA (6 377)	Canada (3 433)	UK (3 318)	Germany (2 761)	Malaysia (2 402)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

are already strong. In 2012, one in seven international students in Malaysia was of Iranian origin (see Figure 26.9). In addition to being one of the rare countries which do not impose visas on Iranians, Malaysia is a Muslim country with a similar level of income. There were about 14 000 foreign students at Iranian universities in 2013, most of whom came from Afghanistan, Iraq, Pakistan, Syria and Turkey. The *Fifth Five-Year Economic Development Plan* has fixed the target of attracting 25 000 foreign students by 2015 (Tehran Times, 2013). In a speech[4] delivered at the University of Tehran in October 2014, President Rouhani recommended establishing an English-language university to attract more foreigners.

Iran is collaborating on international projects via the Organization of Islamic States' Standing Committee on Scientific and Technological Cooperation (COMSTECH). Moreover, in 2008, Iran's Nanotechnology Initiative Council established an Econano network[5] to promote the scientific and industrial development of nanotechnology among members of the Economic Cooperation Organization (see Annex I, p. 736).

Iran hosts several international research centres, including the following established within the past five years under the auspices of the United Nations: the Regional Centre for Science Park and Technology Incubator Development (UNESCO, est. 2010), the International Centre on Nanotechnology for Water Purification (UNIDO, est. 2012) and the Regional Educational and Research Centre for Oceanography for Western Asia (UNESCO, est. 2014).

An economy under pressure

According to Mousavian (2012), the sanctions have slowed Iran's industrial and economic growth, considerably limited foreign investment and triggered national currency devaluation, hyperinflation, declining GDP and, last but not least, a dip in oil and gas production and exports. The sanctions have hit the private sector particularly hard, increasing the costs of finance companies and the credit risk of banks, eroding foreign-exchange reserves and restricting companies' access to foreign assets and export markets. Knowledge-based enterprises have also had limited access to high-quality equipment, research tools, raw materials and technology transfer (Fakhari *et al.,* 2013).

Two other variables have affected Iran's economy: populist policies, which fuelled inflation, and the reform of energy and food subsidies. Some analysts argue[6] that this combination did more harm to the economy than the sanctions and global financial crisis put together (see, for example, Habibi, 2013). They posit that populist policies created an anti-expert discourse, citing President Mahmoud Ahmadinejad's decision to place the Management and Planning Organization under his direct control[7] in 2007. This venerable institution dated from 1948 and was responsible for preparing Iran's medium- and long-term development plans and policies, along with evaluating their implementation.

In January 2010, parliament introduced a reform to remove the energy subsidies which dated from the Iran–Iraq war of the 1980s. These subsidies were costing about 20% of GDP each year and had made Iran one of the most energy-intensive countries in the world. The International Monetary Fund (IMF) has described the reform as 'one of the most courageous moves to reform subsidies in an energy-exporting country' (IMF, 2014).

To cushion the impact on households, the subsidies were replaced by targeted social assistance of the equivalent of about US$ 15 per month that was extended to more than 95% of Iranians. Enterprises were also promised subsidized loans to help them adopt new, energy-saving technologies and credit lines to mitigate the impact of higher energy prices on their production (IMF, 2014). Ultimately, most of these loans have not materialized.[8]

Between 2010 and 2013, inflation climbed from 10.1% to 39.3%, according to the Iranian Statistical Centre. By 2013, the economy had slipped into recession (-5.8%), after growing by 3% in 2011 and 2012. Unemployment remained high but stable, at 13.2% of the the labour force in 2013.

A new team at the economy's bedside

President Rouhani is considered a moderate. Shortly after his election in June 2013, he stated in parliament that 'there must be equal opportunities for women,' before going on to appoint two women vice-presidents and the first woman spokesperson in the Ministry of Foreign Affairs. He has also pledged to expand internet access (26% in 2012). In an interview with NBC News[9] in September 2013, he said that 'we want the people, in their private lives, to be completely free. In today's world, having access to information and the right of free dialogue and the right to think freely is a right of all peoples, including Iranians. The people must have full access to all information worldwide.' In November 2014, he reinstated the Management and Planning Organization.

4. President Rouhani said that 'scientific evolution will be achieved by criticism […] and the expression of different ideas. […] Scientific progress is achieved, if we are related to the world. […] We have to have a relationship with the world, not only in foreign policy but also with regard to the economy, science and technology. […] I think it is necessary to invite foreign professors to come to Iran and our professors to go abroad and even to create an English university to be able to attract foreign students.'

5. See : http://econano.ir

6. See, for example : http://fararu.com/fa/news/213322

7. The Management and Planning Organization was renamed the Presidential Deputy for Strategic Monitoring.

8. The Hi-Tech Development Fund has meanwhile been helping some enterprises to adopt energy-saving technologies. See (in Persian): www.hitechfund.ir

9. See : http://english.al-akhbar.com/node/17069

President Rouhani's domestic priorities are to create an environment more conducive to business and to tackle the acute problems of high unemployment, hyperinflation and inadequate purchasing power: GDP per capita amounted to PPP$ 15 586 (in current prices) in 2012, less than the previous year (PPP$ 16 517).

In 2014, the president instituted two major projects. The first was the *Second Phase of the Subsidy Reform Plan* initiated by his predecessor, which entailed a 30% price rise on petrol. His second major project has been the *Health Overhaul Plan*. This plan reduces the cost of treatment for patients in state-run hospitals from 70% to 5% in rural areas and 10% in urban areas. About 1.4 million patients have been admitted to state-run hospitals since the plan's inception. Some 3 000 specialists have been employed by the ministry to work in vulnerable regions, 1 400 of whom had taken up their positions by the end of 2014. According to Iran's health minister, the plan is not facing any financial problems in its first two years of operation but some health policy experts worry that the government may not be able to pursue this policy for long, owing to the high cost. Six million people have received health insurance since the plan's implementation, according to the health minister, most of them from the poorer echelons of society.

According to the Iranian economic journalist Saeed Leylaz, 'the country's economic condition was not predictable in the past government but the current government has managed to stabilize the economy. This helped make people reluctant to buy dollars for the purpose of saving. The government has also reduced political tensions and refrained from impulsive acts in the economy' (Leylaz, 2014).

Iran's economic outlook is brighter, thanks partly to the resumption of negotiations with the P5+1. The Iranian Central Bank announced growth of 3.7% in 2014, inflation was down to 14.8% and the unemployment rate down to 10.5%. Non-oil exports are growing. Iran nevertheless remains highly dependent on oil. The *Wall Street Journal* estimated that Iran needed a crude oil brent of US$ 140 in 2014 to balance its budget, the year world oil prices tumbled from US$ 115 to US$ 55 between June and December (see Figure 17.2).

Fluctuating global oil prices have spawned fresh challenges. Iran has recently been using new technologies like hydroconversion in its terminals to diversify its oil products. The sharp decline in the price of crude oil since 2014 may prevent the government from investing as much as it would like in research and development (R&D) into advanced oil extraction technologies. An alternative would be for Iran to develop these technologies jointly with Asian oil companies.

TRENDS IN STI GOVERNANCE

Sanctions precipitating shift to a knowledge economy

They say that every cloud has a silver lining. Indirectly, international sanctions have had some benefits for science, technology and innovation (STI):

- *Firstly,* they have accelerated the shift from a resource-based economy to a knowledge economy. There tends to be a weak link between the oil industry and other socio-economic sectors. Companies deprived of oil and gas revenue have shown a propensity to export technical and engineering services to neighbouring countries. According to a report by the Mehr news agency in November 2014 which cited the deputy energy minister for international affairs, Iran currently exports water and technological power services worth over US$ 4 billion to more than 20 countries.[10]
- *Secondly,* the sanctions have helped to reconcile R&D with problem-solving and public interest research, after years of high oil receipts had divorced science from socio-economic preoccupations.
- *Thirdly*, the sanctions have helped small and medium-sized enterprises (SMEs) develop their businesses by erecting barriers to foreign imports and encouraging knowledge-based enterprises to localize production. With unemployment high and Iranians well-educated, they have had no difficulty recruiting trained staff.
- *Fourthly,* by isolating Iranian companies from the outside world, the sanctions have forced them to innovate.
- *Last but not least,* the sanctions have persuaded policy-makers of the need to embrace the knowledge economy.

The government's policy of developing a knowledge economy is reflected in its *Vision 2025* document adopted in 2005, which offers a recipe for turning Iran into the number one economy in the region[11] and one of the top 12 economies in the world by 2025.

Vision 2025 foresees an investment of US$ 3.7 trillion by 2025 to achieve this goal, nearly one-third of which (US$ 1.3 trillion) is to come from foreign sources. Much of this amount is to go towards supporting investment in R&D by knowledge-based firms and the commercialization of research results. A law was passed in 2010 to provide an appropriate funding mechanism, the Innovation and Prosperity Fund, which became effective in 2012 (see p. 394).

10. including Afghanistan, Azerbaijan, Ethiopia, Iraq, Kenya, Oman, Pakistan, Sri Lanka, Syria, Tajikistan and Turkmenistan

11. *Vision 2025* defines this region as encompassing: Afghanistan, Armenia, Azerbaijan, Bahrain, Egypt, Georgia, Iran, Iraq, Israel, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Lebanon, Oman, Pakistan, Palestine, Qatar, Saudi Arabia, Syria, Tajikistan, Turkey, Turkmenistan, United Arab Emirates, Uzbekistan and Yemen.

Given the persistently low level of foreign direct investment (FDI) – just 0.8% of GDP in 2013 – coupled with Iran's economic woes, several of *Vision 2025's* goals seem unrealistic. A classic example is the target of raising gross domestic expenditure on R&D (GERD) to 4% of GDP by 2025. Other goals seem within reach, such as that of tripling the number of scientific articles to 800 per million population (Table 15.1).

In 2009, the government adopted a *National Master Plan for Science and Education* to 2025 which reiterates the goals of *Vision 2025*. It lays particular stress on developing university research and fostering university–industry ties to promote the commercialization of research results.

A focus on fostering innovation and excellence

The country's successive five-year development plans set out to realize collectively the goals of *Vision 2025*. Adopted by law, these plans also provide the most important institutional basis for STI policy in Iran. The current *Fifth Five-Year Economic Development Plan* covers the period from 2010 to 2015. The chapters relative to higher education and STI policy complement those of the *National Master Plan for Science and Education*.

Under the section on social affairs, the *Fifth Five-Year Economic Development Plan* speaks of developing indicators to measure the quality of the air, food and the environment in general, and undertakes to reduce health-threatening pollution. It also vows to reduce the population's share of health costs to 30% by 2015.

The *Fifth Development Plan* has two main thrusts relative to STI policy. The first is the 'islamization of universities,' which has become a political topic in Iran. The second thrust is to secure second place for Iran in the region in science and technology (S&T) by 2015, which would place it behind Turkey.

The notion of the islamization of universities is open to broad interpretation. The aim seems to be to nationalize scientific knowledge in the humanities and bring it into line with Islamic values, while developing student morals and spirituality. According to Article 15 of the *Plan*, university programmes in the humanities are to be modified as part of this strategy and students are to be taught the virtues of critical thinking, theorization and multidisciplinary studies. A number of research centres are also to be developed in the humanities.

Table 15.1: **Key targets for education and research in Iran to 2025**

	Situation in 2013	Vision 2025 targets
Share of adults with at least a bachelor's degree	–	30%
Share of PhD holders among total students	1.1%-1	3.5%
Researchers (FTE) per million population	736-3	3 000
Government researchers (share of total researchers)	33.6%-5	10%
Researchers in business enterprise sector (share of total researchers)	15.0%-5	40%
Share of researchers employed by universities*	51.5%-5	50%
Full-time university professors per million population	1 171	2 000
Scientific articles per million population	239	800
Average citations per publication **	0.61-2	15
Number of Iranian journals with an impact factor of more than 3	–	160
Number of national patents	–	50 000
Number of international patents	–	10 000
Public expenditure on education as a share of GDP	3.7%	7.0%
Public expenditure on higher education as a share of GDP	1.0%-1	–
GERD/GDP ratio	0.31%-3	4.0%
Share of GERD financed by business enterprise sector	30.9%-5	50%
Share of articles among 10% most cited worldwide	7.7%-2	–
Number of articles among 10% most cited worldwide	1 270-2	2 250
Number of Iranian universities in top 10% worldwide	0	5

*includes religious centres

**average relative citations; the OECD average in 2011 was 1.16

-n/+n refers to *n* years before reference year

Source: for 2025 targets: Government of Iran (2005) *Vision 2025*; for current situation, Statistical Centre of Iran and UNESCO Institute for Statistics

The following strategies have been devised to secure second place for Iran in S&T in the region:

- a comprehensive system is to be put in place for monitoring, evaluating and ranking institutions of higher education and research institutes. The Ministry of Science, Research and Technology and the Ministry of Health and Medical Education have been entrusted with this task. Researchers will be evaluated on the basis of criteria such as their scientific productivity, their involvement in applied R&D or the problem-solving nature of their work;
- in order to ensure that 50% of academic research is oriented towards socio-economic needs and problem-solving, promotion is to be tied to the orientation of research projects. In addition, mechanisms are to be put in place to enable academics to enrol in further education, take sabbaticals and explore new research opportunities. Research and technology centres are also to be set up on campus and universities are to be encouraged to develop linkages with industry;
- The number of university graduate programmes in applied disciplines is to increase;
- Each university is to be endowed with an academic board that oversees implementation of the academic programme;
- Laboratories in applied science are to be set up and equipped at universities, other educational institutions, in science and technology parks and business incubators by public research institutions and their subsidiaries;
- The GERD/GDP ratio is to increase by 0.5% each year to attain 3% by 2015;
- FDI is to account for 3% of GDP by 2015;
- Scientific ties are to be developed with prestigious international educational and research institutions;
- An integrated monitoring and evaluation system is to be put in place for S&T;
- Major indicators of S&T are to be incorporated in government planning, including the volume of revenue generated by exports of medium-tech and high-tech goods, the share of GDP per capita derived from S&T, the number of patents, the share of FDI in scientific and technological activities, the cost of R&D and the number of knowledge-based companies.

The following priorities focus on technology diffusion and support for knowledge-based companies:

- Priority is to be given in the annual R&D budget of ministries to financing demand-driven research and to supporting the development of private and co-operative SMEs which commercialize knowledge and technology and turn them into export products; the government is to encourage the private sector to set up business incubators and science and technology parks and to encourage foreign parties to invest in technology transfer and R&D, in partnership with domestic companies; foreign investors are also to be encouraged to finance patents; the government is to support the establishment of totally private knowledge-based companies by universities; innovators and leaders in science are to receive targeted financial and intellectual support from the government to support the commercialization of their inventions; the government is to make provisions for the payment of patent application costs at both national and international levels and, lastly, to make arrangements for the commercial release of their product or service (Articles 17 and 18);
- The Ministry of Communications and Information Technology is to develop the necessary infrastructure, such as the installation of fibre optics, to ensure broadband internet access, to enable universities, research bodies and technological institutions to network and share information and data on their respective research projects, intellectual property issues and so on (Article 46);
- A National Development Fund (Articles 80–84) is established to finance efforts to diversify the economy; preserve part of oil and gas rents for future generations; and increase the return on income from accumulated savings; by 2013, the Fund was receiving 26% of oil and gas revenue – the ultimate goal is to reserve 32% of this revenue for the Fund (IMF, 2014);
- New campuses are to be launched in special economic zones by public and private Iranian universities and international leading universities (Article 112);
- Closer ties are to be forged between small, medium-sized and large businesses and, in parallel, industrial clusters are to be set up. Private sector investment is to be encouraged to develop the value chain of downstream industries (petrochemicals, basic metals and non-metallic mineral products), with an emphasis on the establishment of professional industrial estates and the development of closer linkages between industry and science and technology parks to develop capacity for industrial design, procurement, innovation and so on (Article 150).

The pivotal role of the Innovation and Prosperity Fund

The Innovation and Prosperity Fund functions under the Deputy for Science and Technology. It was established in 2012 to support investment in R&D by knowledge-based firms and the commercialization of research results.

According to the Fund's president, Behzad Soltani, 4 600 billion Iranian rials (*circa* US$ 171.4 million) had been allocated to 100 knowledge-based companies by late 2014. Sorena Sattari, Vice-President for Science and Technology, declared[12] on 13 December 2014 that, 'in spite of the difficulties the country is confronting, 8 000 billion rials have been attributed to the Innovation and Prosperity Fund for 2015.'

The Innovation and Prosperity Fund is the primary policy instrument for ensuring the implementation of Articles 17 and 18 of the *Fifth Five-Year Economic Development Plan:*

- National organizations wishing to conduct problem-solving research may apply for the allocation of facilities and partnering to the Secretariat of the Working Group for the Assessment and Identification of Knowledge-based Companies and Institutions and Supervision of Project Implementation.
- Universities wishing to set up fully private companies may also apply to the fund; as of December 2014, public and private universities from four Iranian provinces had applied to establish knowledge-based companies in special economic zones (Article 112): Tehran, Isfahan, Yazd and Mashhad. These applications are still under review, according to the Supreme Council of Science, Research and Technology.
- The fund also supports SMEs by offering tax incentives and paying partial costs of commercializing knowledge and technology; it also covers part of the interest on bank loans contracted for the purchase of equipment, the setting up of production lines, testing and marketing, etc.;
- The fund also offers financial support to private companies wishing to set up business incubators and science and technology parks then facilitates the establishment of these centres through such measures as the provision of rent-free premises and tax incentives.

The fund is also intended to encourage foreign parties to invest in technology transfer and R&D but this ambition has been somewhat thwarted by the international sanctions; foreign companies may still invest in patents, however.

Innovators and leaders in science receive intellectual and financial support from the National Elites Foundation, which was set up[13] in 1984. In December 2013, a new department was created within the foundation, called the Deputy of International affairs. It aims to harness the talent of non-resident Iranians to improve domestic capacity in S&T and take advantage of the experience of the diaspora. The foundation tailors its services to four different groups: Iranian PhD graduates from the world's top universities; Iranian professors teaching in the world's top universities; Iranian experts and managers heading the world's top scientific centres and companies in technological fields and, lastly, non-resident Iranian investors and entrepreneurs who have succeeded in technological fields. The eligibility criteria were revised in 2014 to include groups as well as individuals and research expertise and experience as well as academic performance. The selection of elites has also been delegated to the universities. Additional incentive measures have been introduced, such as grants for research visits to top universities abroad and research grants from day one of a faculty member's career.

Enter the 'economy of resistance'

On 19 February 2014, the Supreme Leader Ayatollah Ali Khamenei introduced, by decree, what he termed Iran's 'economy of resistance.' This economic plan outlines strategies for making Iran more resilient to sanctions and other external shocks. It essentially reasserts the goals of *Vision 2025*, which is why some key provisions will sound familiar.

Coming when it did, some analysts see the economy of resistance as an endorsement of the new government's comprehensive economic reform, after the previous administration's relative indifference towards *Vision 2025* caused it to veer off course. For Khajehpour (2014a), a managing partner at Atieh, a group of strategic consulting firms based in Tehran, Iran 'has all the resources that an economy would need to play a much more significant role on the international stage. The missing links are in the areas of responsible and accountable policy-making, legal transparency and modern institutions.'

Key provisions of the 'economy of resistance' include (Khajehpour (2014a):

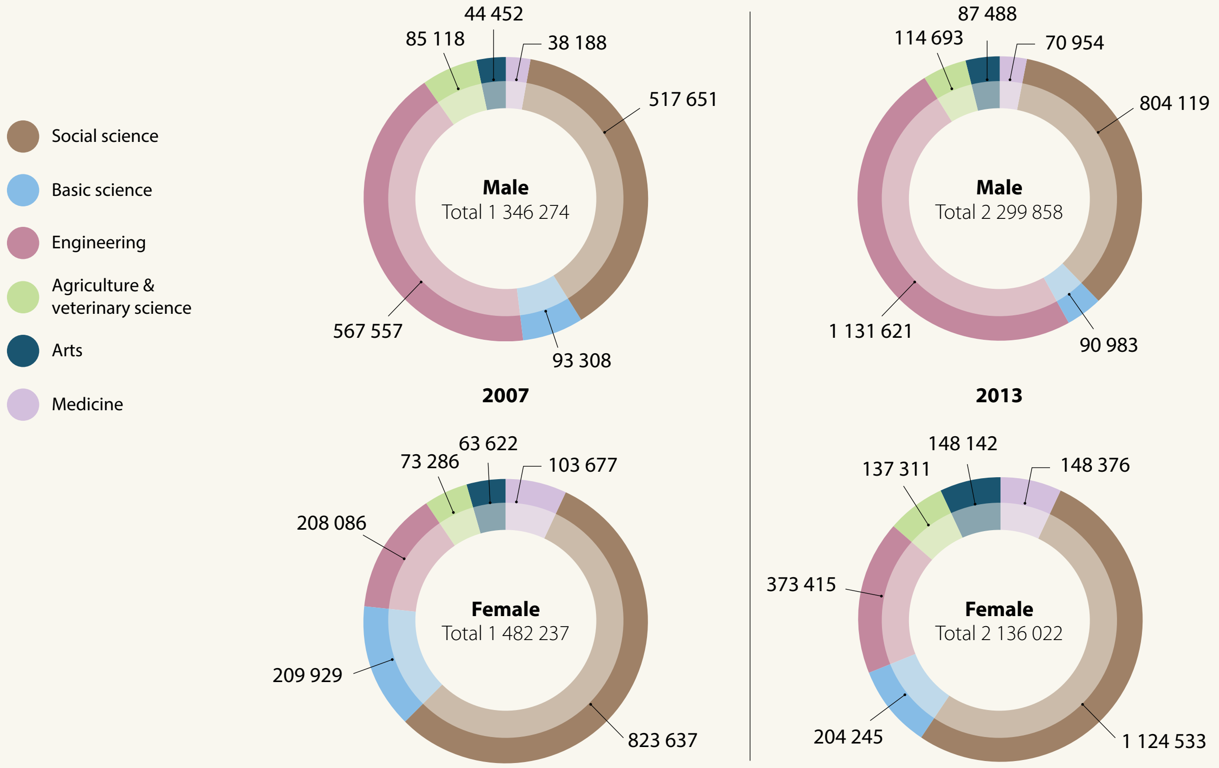
- promoting a knowledge-based economy through the drafting and implementation of a comprehensive scientific plan for the country and the promotion of innovation, the ultimate goal being to become the top knowledge-based economy in the region;
- utilizing the reform of subsidies to optimize energy consumption in the country, increase employment and domestic production and promote social justice;
- promoting domestic production and consumption, especially in strategic products and services, to reduce dependence on imports, while improving the quality of domestic production;
- providing food and medicine security;
- promoting exportable goods and services through legal and administrative reform, while promoting FDI for export purposes;

12. See (in Persian): www.nsfund.ir/news

13. See: http://en.bmn.ir

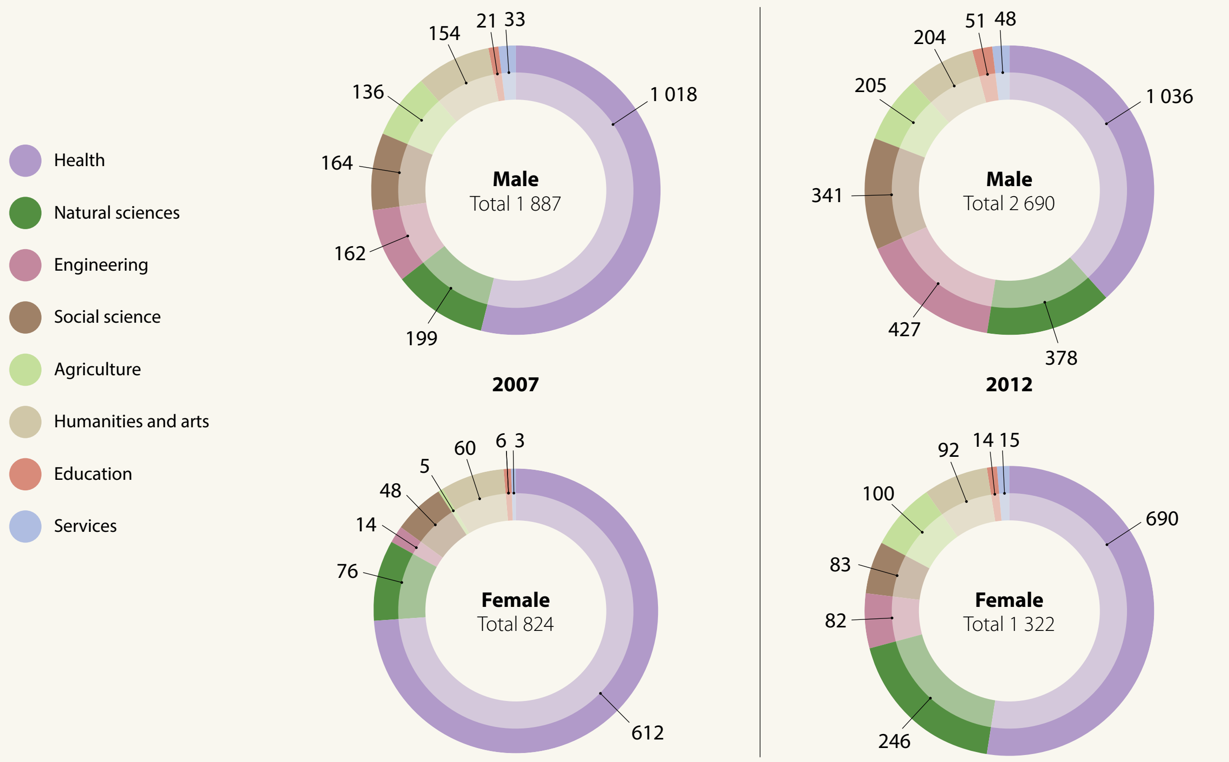
Figure 15.2: **Students enrolled in Iranian universities, 2007 and 2013**

Both public and private universities



Source: Iranian Statistical Centre (2014) *Statistical Yearbook*

Figure 15.3: **PhD graduates in Iran by field of study and gender, 2007 and 2012**



Source: UNESCO Institute for Statistics

- increasing the economy's resistance through regional and international economic collaboration, especially with neighbours but also through diplomacy;
- increasing oil and gas value-added exports;
- implementing reforms to rationalize government costs, increase tax revenues and reduce dependency on oil and gas export revenue;
- increasing the share of the National Development Fund from oil and gas export revenues;
- increasing transparency in financial matters and avoiding activities that pave the way for corruption.

TRENDS IN HUMAN RESOURCES AND R&D

Strong growth in students but no rise in R&D intensity

Between 2005 and 2010, policy-makers focused on increasing the number of academic researchers, in line with *Vision 2025.* To this end, the government raised its commitment to higher education to 1% of GDP in 2006 and has since maintained this level, even as public expenditure on education overall has slipped from 5.1% (2006) to 3.7% (2013) of GDP.

The result has been a steep rise in tertiary enrolment. Between 2007 and 2013, student rolls swelled from 2.8 million to 4.4 million in the country's public and private universities (Figure 15.2). There were more women students than men in 2007 but their proportion has since dropped back slightly to 48%. Some 45% of students were enrolled in private universities in 2011 (UIS, 2014).

Enrolment has progressed in most fields, with the exception of natural sciences where it has remained stable. The most popular fields are social sciences (1.9 million students) and engineering (1.5 million). There are more than 1 million men studying engineering and more than 1 million women studying social sciences. Women also make up two-thirds of medical students.

The number of PhD graduates has progressed at a similar pace (Figure 15.3). Natural sciences and engineering have proved increasingly popular among both sexes, even if engineering remains a male-dominated field. In 2012, women made up one-third of PhD graduates, being drawn primarily to health (40% of PhD students), natural sciences (39%), agriculture (33%) and humanities and arts (31%). According to the UNESCO Institute for Statistics, 38% of master's and PhD students were studying S&T fields in 2011 (UIS, 2014).

Although data are not readily available on the number of PhD graduates choosing to stay on as faculty, the relatively modest level of GERD would suggest that academic research suffers from inadequate funding. A study by Jowkar *et al.* (2011) analysed the impact of 80 300 Iranian articles published between 2000 and 2009 in Thomson Reuter's Science Citation Index Expanded; it found that about 12.5% of these publications were funded and that the citation rate of funded publications was higher in almost all subject fields. The greatest share of funded publications came from universities subordinate to the Ministry of Science, Research and Technology.

Even though one-third of GERD came from the business sector[14] in 2008, this contribution remains too small to nurture innovation effectively – it represents just 0.08% of GDP. GERD even dropped between 2008 and 2010 from 0.75% to 0.31% of GDP. In this context, the target identified in the *Fifth Five-Year Development Plan* (2010–2015) of devoting 3% of GDP to R&D by 2015 looks elusive, to say the least.

According to the UNESCO Institute for Statistics, the number of full-time equivalent (FTE) researchers rose from 711 to 736 per million inhabitants between 2009 and 2010. This corresponds to an increase of more than 2 000 researchers, from 52 256 to 54 813.

Businesses are performing more R&D than before

In 2008, half of researchers were employed in academia (51.5%), one-third in the government sector (33.6%) and just under one in seven in the business enterprise sector (15.0%).

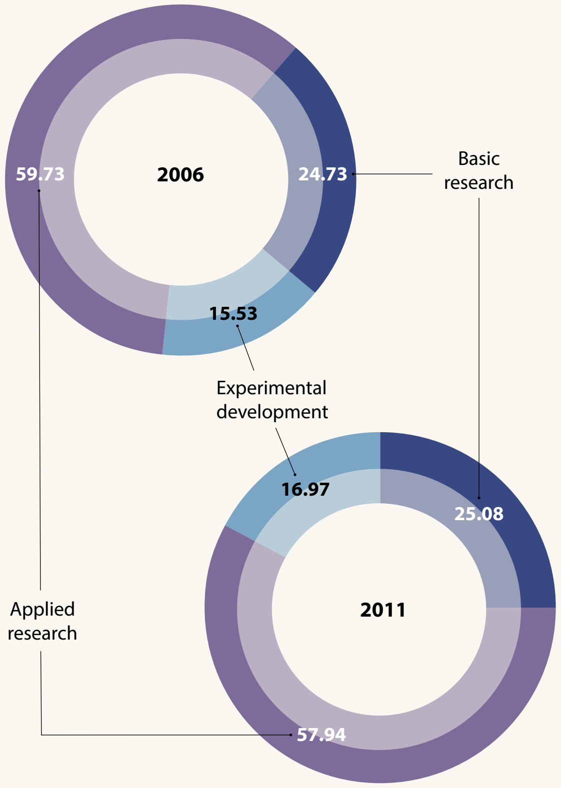
Between 2006 and 2011, the number of firms declaring R&D activities more than doubled, however, from 30 935 to 64 642. Once more recent data become available, we may find that the business enterprise sector has been hiring more researchers than before. So far, there has been little change in the focus of industrial R&D, with firms still conducting mainly applied research (Figure 15.4).

More articles but few technological spin-offs

One priority of STI policy in recent years has been to encourage scientists to publish in international journals. Again, this is in line with *Vision 2025*. As we have seen, the share of internationally co-authored articles has remained relatively stable since 2002. The volume of scientific articles has augmented considerably, on the other hand, even quadrupling by 2013 (Figure 15.1). Iranian scientists now publish widely in international journals in engineering and chemistry, as well as in life sciences and physics. Contributing to this trend is the fact that PhD programmes in Iran now require students to have publications in the Web of Science. Women contribute only about 13% of articles, with a focus on chemistry, medical sciences and social sciences, according to Davarpanah and Moghadam (2012).

14. Data are unavailable for a more recent breakdown by sector.

Figure 15.4: **Focus of Iranian firms by type of research, 2006 and 2011 (%)**



Source: Iranian Statistical Centre

This productivity gain has had little effect on the production of technology, however. In nanotechnology, for instance, Iranian scientists and engineers were only granted four patents by the European Patent Office between 2008 and 2012. The lack of technological output results mainly from three shortcomings in the innovation cycle. The first among these shortcomings is the failure to co-ordinate executive and legal power structures to strengthen intellectual property protection and the wider national innovation system, despite this being a key policy objective for over a decade now. In the *Third Five-Year Development Plan, 2000–2004,* the co-ordination of all scientific activities was entrusted to the Ministry of Science, Research and Technology, to avoid overlap with other ministries (health, energy, agriculture, etc.). The post of Presidential Deputy for Science and Technology[15] was likewise created in 2005 to centralize the budget and planning of all S&T activities. Little has been done since, however, to improve co-ordination between administrative bodies in the executive branch and judiciary.

The past few years have witnessed persistent inattention to problem-solving in decision-making and little effort to improve the country's inadequate system of intellectual property protection. These two shortcomings do more to weaken the national innovation system than either the lack of available venture capital or the international sanctions.

Why the persistent inattention to problem-solving, despite a plethora of documents? This is because public policy in Iran combines strategic planning with poetic idealism. Official policy documents are a mixture of declarations of intent and copious recommendations – even though, when everything is a priority, nothing is. A more complex and detailed alternative is required, a planning model that does not elaborate recommendations until the issues and related policy questions have first been clearly defined and the legal context analysed, a model which comprises an implementation plan and a rigorous monitoring and evaluation system.

PRIORITY AREAS FOR R&D

Most high-tech companies are state-owned

Some 37 industries trade shares on the Tehran Stock Market. These industries include the petrochemical, automotive, mining, steel, iron, copper, agriculture and telecommunications industries, a unique situation in the Middle East.

Most of the companies developing high technology in Iran are state-owned. The Industrial Development and Renovation Organization (IDRO) controls about 290 of them. IDRO has also set up special purpose companies in each high-tech sector[16] to co-ordinate investment and business development. In 2010, IDRO set up a capital fund to finance the intermediary stages of product- and technology-based business development.

Some 80% of state-owned firms are due to be privatized over the ten years to 2014, further to an amendment to Article 44 of the Constitution in 2004. In May 2014, Tasnim News Agency quoted Abdollah Pouri Hosseini, the head of the Iran Privatization Organization, as saying that Iran would be privatizing 186 state-run companies in the new year (beginning 21 March 2014 in Iran). Twenty-seven of these companies have a market value each in excess of US$ 400 million, he said. Several key industries remain largely state-owned, however, including the automotive and pharmaceutical industries (Boxes 15.1 and 15.2).

Iran's R&D priorities are reflected in their share of government outlay (Table 15.2). In basic and applied science, the priority fields

15. In Iran, each vice-president has several deputies. Under the Vice-President for Science and Technology, for instance, there is a Deputy for Science and Technology, a Deputy for Management Development and Resources and a Deputy for International Affairs and Technological Exchange.

16. These entities are the Life Science Development Company, Information Technology Development Centre, Iran InfoTech Development Company and the Emad Semiconductor Company.

are dense matter, stem cells and molecular medicine, energy recycling and conversion, renewable energies, cryptography and coding. The priority technological industries are aerospace, ICTs, nuclear technology, nanotechnology and microtechnologies, oil and gas, biotechnology and environmental technologies.

In aerospace, Iran manufactures aeroplanes, helicopters and drones. It is currently developing its first wide-body plane[17] to improve seating capacity, as the country only has about nine aircraft per million population. The industry plans to shift its focus from 59-seaters to planes that can seat 90–120 passengers, as long as it can import the relevant technical knowledge.

Meanwhile, the Iranian Space Agency has built a number of small satellites that are launched into low-Earth orbit using a locally produced carrier rocket called Safir. In February 2012, Safir transported its biggest satellite yet, weighing 50 kg (Mistry and Gopalaswamy, 2012).

17. After purchasing the production license for the An-140 from Ukraine in 2000, Iran built its first Iran-140 commercial passenger plane in 2003.

A growing role in biotechnology and stem cell research

Research in biotechnology has been overseen by the Iranian Biotechnology Society since 1997. Iran maintains three important health research[18] facilities. Two of these, the Pasteur Institute and the National Research Centre for Genetic Engineering and Biotechnology, study human pathologies. The third, the Razi Institute for Serum and Vaccines, studies both human and animal diseases. The Razi and Pasteur Institutes have been developing and producing vaccines for humans and livestock since the 1920s. In agricultural biotechnology, researchers are hoping to improve crop resistance to pests and disease. The Persian Type Culture Collection is a subordinate of the Biotechnology Research Centre in Tehran, which falls under the umbrella of the Iranian Research Organization for Science and Technology (IROST); it provides services to both private industry and academia.

18. See: www.nti.org/country-profiles/iran/biological

Box 15.1: **Automobiles dominate Iranian industry**

After oil and gas, the automotive industry is Iran's biggest, accounting for about 10% of GDP and employing about 4% of the labour force. There was a boom in local car manufacturing between 2000 and 2013, driven by high import duties and a growing middle class. In July 2013, sanctions imposed by the USA prevented Iranian companies from importing the vehicle parts upon which domestic cars rely; this caused Iran to cede its place to Turkey as the region's top vehicle manufacturer.

The Iranian car market is dominated by Iran Khodro (IKCO) and SAIPA, which are subsidiaries of the state-owned Industrial Development and Renovation Organization. SAIPA (standing for *Société anonyme iranienne de production automobile)* was founded in 1966 to assemble French Citroën cars under license for the Iranian market. IKCO was founded in 1962 and, like SAIPA, assembles European and Asian cars under license, as well as its own brands.

In 2008 and 2009, the government spent over US$ 3 billion on developing infrastructure to enable vehicles to run on compressed natural gas. The aim was to reduce costly petrol imports due to an insufficient refining capacity in Iran. With the world's biggest natural gas reserves after the Russian Federation, Iran rapidly became the world leader for the number of vehicles running on natural gas: by 2014, there were over 3.7 million on the road.

In 2010, the government reduced its participation in both companies to about 20% but the deals were annulled the same year by the Iranian Privatization Organization.

IKCO is the biggest car manufacturer in the Middle East. In 2012, it announced that it would henceforth be reinvesting at least 3% of company sales revenue in R&D.

For years, Iranian carmakers have used nanotechnology to increase customer satisfaction and safety by providing such comforts as anti-stain dashboards, hydrophobic glass planes and anti-scratch paint. In 2011, the Nanotechnology Initiative Council announced plans to export to Lebanon a series of 'home-made' nano-based engine oils manufactured by the Pishgaman–Nano-Aria Company (PNACO); these nano-based oils reduce engine erosion, fuel consumption and engine temperature. In 2009, researchers at Isfahan University of Technology developed a strong but light nanosteel as resistant to corrosion as stainless steel for use in road vehicles but also potentially in aircraft, solar panels and other products.

The sanctions imposed in 2013 hit exports particularly hard, which had doubled to about 50 000 cars between 2011 and 2012. This prompted IKCO to announce plans in October 2013 to begin selling 10 000 cars a year to the Russian Federation. Traditional export markets include Syria, Iraq, Algeria, Egypt, Sudan, Venezuela, Pakistan, Cameroon, Ghana, Senegal and Azerbaijan. In 2014, French car-makers Peugeot and Renault resumed their traditional business with Iran.

Source: http://irannano.org; Rezaian (2013); Press TV (2012)

Table 15.2: **Government outlay for R&D in Iran by major agency, 2011**

	R&D centre	Budget (million rials)
Deputy for Science and Technology		1 484 125
Supports the following R&D centres	Nanotechnology Initiative Council	482 459
	Centre for the Development of Knowledge-Based Companies	110 000
	Biotechnology Research Centre	100 686
	Centre for the Development of Drugs and Traditional Medicine	90 000
	Centre for Stem Cell Research	75 000
	Centre for New Energy Development	65 000
	Centre for ICT Development and Microelectronics	60 000
	Centre for Cognitive Science	56 274
	Centre for Water, Drought, Erosion and Environmental Management	50 000
	Centre for Software Technologies	10 000
Ministry of Science, Research and Technology		1 356 166
	Iranian Space Agency	85 346
	Iranian Research Organization for Science and Technology	357 617
Ministry of Defence		683 157
Ministry of Health and Medical Training		656 152
Ministry of Industry		–
	Industrial Development and Renovation Organization	536 980
	Iranian Fisheries Research Organization	280 069
	Iran Aviation Industries Organization	156 620
Ministry of Energy		38 950
	Atomic Energy Organization	169 564
	Research Institute of the Petroleum Industry	480 000
	Renewable Energy Organization (SUNA)	12 000
Ministry of Information and Communication Technology		440 000
Ministry of Agriculture		86 104
Other		33 147 411
	95 universities and 72 institutions affiliated to the Ministry of Science, Research and Technology	
	84 universities and 16 institutions affiliated to the Ministry of Health and Medical Training	
	22 universities and institutions affiliated to the Ministry of Defence	
	32 science and technology parks	
	184 institutions affiliated to the Ministries of Industry and Agriculture	
	23 institutions affiliated to the Presidency	
	63 other organizations	
Total		**41 069 680**

Note: The three following centres were established in 2014 under the Deputy for Science and Technology: the Centre for Oil, Gas and Coal Research; Centre for the Optimization of Energy and the Environment; and the Centre for Knowledge-based Marine Companies. The budget for each ministry does not cover the universities and other institutions associated with it.

Source: www.isti.ir; compiled by author with input from the National Research Institute for Science Policy

Box 15.2: The ups and downs of Iran's pharmaceutical industry

There are currently 96 local manufacturers in Iran which produce some 30 billion units of medicine worth about US$ 2 billion per year. Local production covers about 92% of the Iranian market but does not include high-quality drugs needed for the specific treatment of diabetes, cancer, etc. These drugs need to be imported, at a cost of about US$ 1.5 billion. As the market volume represents US$ 3.5 billion, this means that 43% of demand is met through imports.

Of the 96 local companies, about 30 control 85% of the market. The biggest four players are Daroupakhsh, Jaberebne Hayyan, Tehran Shimi and Farabi, in descending order. These four companies alone account for more than 20% of the market. Local manufacturers still rely on outdated production lines, making the cost of pharmaceutical manufacturing relatively high in Iran and thus expensive for consumers.

Foreign pharmaceutical companies in Iran usually operate either directly through their branch offices or through dealerships with Iranian pharmaceutical companies authorized to sell their products.

In Iran, per capita expenditure on medicine stood at US$ 46 in 2011. The pharmaceutical industry has a profit margin of about 14%. This is three times the profit margin of the Iranian automotive industry. Most pharmaceutical companies are state-owned or quasi-governmental entities, although some are listed on the Tehran Stock Exchange. The private sector's share of the market only amounts to about 30%. Pharmaceutical companies export drugs to about 30 countries, for a market value of US$ 100 million per year.

Under the Ministry of Health and Medical Education, it is the Department of Foods and Drugs which is directly responsible for supervising pharmaceutical companies. The government tends to make all strategic decisions and monitors standards, quality and the payment of subsidies to recipient companies.

In recent years, there has been a growing emphasis on local production and exports to regional markets. Export destinations include Afghanistan, Iraq, Yemen, the United Arab Emirates and Ukraine.

Although the pharmaceutical sector is not included in the sanctions regime – even US pharmaceutical companies can easily apply for licenses from the US Treasury's Office of Foreign Assets Control to export goods to Iran – it is severely undermined by the blanket banking sanctions. Iranian importers complain that Western banks have been declining to enter into transactions related to pharmaceutical imports into Iran. In fact, it is the banking and insurance sanctions which have been the main irritant for all Iranian businesses.

Some Western companies have also reduced their business dealings with Iranian pharmaceutical companies out of fear of contravening the sanctions. This is limiting imports of high-tech machinery, equipment and medicine, including essential drugs for diseases such as cancer, diabetes and multiple sclerosis. Imports from US and European drug-makers were down by 30% in 2012, forcing Iranian companies to import drugs of a lower standard from Asia. The shortage has also pushed up prices, as substitution is not an option in the highly patented world of pharmaceuticals, putting many drugs beyond the reach of the average Iranian. The sanctions also leave Iran short of the hard currency needed to pay for Western drugs.

Source: Khajehpour (2014b); Namazi (2013)

Iranian scientists publish less in agricultural sciences than in medical sciences, although the number of articles has progressed considerably in both fields since 2005. Iran is a growing destination for medical tourism in the Middle East. The Royan Institute, for instance, is a beacon for infertile couples (Box 15.3).

Iran has become a hub for nanotech

Nanotech research has taken off in Iran since the Nanotechnology Initiative Council (NIC)[19] was founded in 2002 (Figure 15.5). NIC's budget increased considerably between 2008 and 2011, from 138 million to 361 million rials; NIC received a lesser endowment in 2012 (251 million rials) but this has since rebounded to 350 million rials (2013).

NIC is tasked with determining the general policies for the development of nanotechnology in Iran and with co-ordinating their implementation. It provides facilities, creates markets and strives to help the private sector develop relevant R&D activities.

There are several nanotechnology research centres in Iran:

- the Nanotechnology Research Centre at Sharif University (est. 2005), which established Iran's first doctoral programme in nanoscience and nanotechnology;
- the Nanotechnology Research Centre at Mashhad University of Medical Sciences within the Mashhad Bu Ali Research Institute (est. 2009);

19. See: www.irannano.org

Box 15.3: The Royan Institute: from infertility treatments to stem cell research

The Royan Institute was founded by Dr Saeid Kazemi Ashtiani in 1991 as a public non-profit research institute for reproductive biomedicine and infertility treatments. It publishes the *Cell Journal* and the *Iranian Journal of Fertility and Sterility*, both of which are indexed in Thomson Reuters' Web of Science. The institute has its own annual prize, the Royan International Research Award.

The Royan Institute is administered by the Jihad Daneshgahi (*jihad* here means sacred effort in a scientific domain), which itself comes under the supervision of the Council of the Cultural Revolution. The institute is officially non-governmental but is, in fact, part of the higher education system and thus government-funded.

In 1998, the institute was approved by the Ministry of Health as a cell-based research centre. Today, it employs 46 scientists and 186 laboratory technicians in three separate institutes: the Royan Institute for Stem Cell Biology and Technology; the Royan Institute for Reproductive Biomedicine; and the Royan Institute for Animal Biotechnology.

One of the institute's first achievements was the birth of a child conceived using *in vitro* fertilization techniques in 1993. A decade later, the institute set up a stem cell research department. In 2003, it developed human embryonic cell lines for the first time. In 2004, researchers succeeded in obtaining insulin-producing cells from human embryonic stem cells. Adult stem cells have been used to treat corneal injuries (to the eye) and myocardial infarctions (heart attacks) in humans.

In 2011, the Royan Institute set up a Stem Cell Bank and a cell-therapy pre-hospital. A year later, the first healthy child was born after being treated for beta-thalassemia, a disease caused by a defect in the gene responsible for producing haemoglobin, an iron-rich protein contained in red blood cells. About 5% of the world's population are healthy carriers of a gene for haemoglobin disorders but these are most common in Asia, the Middle East and the Mediterranean Basin.

Among other achievements, one could cite the birth of the first cloned sheep in Iran in 2006 and that of the first cloned goat in 2009.

The Royan Institute established the Cord Blood Bank in Iran in 2005. In November 2008, the Bank announced that US$ 2.5 billion would be invested in stem cell research over the next five years and that stem cell research centres would be opened in all major cities.

Source: www.royaninstitute.org; PressTV (2008)

- the Medical Nanotechnology and Tissue Engineering Research Centre at the Shahid Beheshti University of Medical Sciences;
- the Nanotechnology Research Centre at Jondi Sapoor University (est. 2010); and
- the Zanjan Pharmaceutical Nanotechnology Research Centre at Zanjan University of Medical Sciences (est. 2012).

Iran's nanotechnology programme is characterized by the following features (Ghazinoory *et al*., 2012):

- policy-making is a top-down process led by the government;
- the programme is futuristic (forward-looking);
- it relies heavily on promotional efforts to stimulate an interest in nanotechnology among policy-makers, experts and the general public, including an annual Nanotechnology Festival in Tehran; the NIC has created a Nano Club[20] for school students and a Nano Olympiad;
- it places emphasis on making all the links in the value chain;
- it makes wide usage of financial support as an incentive;
- it is supply-based, as opposed to needs-based, and relies on Iran's domestic capabilities.

In nanotech, quantity still outstrips quality

One of NIC's missions has been to hoist Iran among the top 15 countries in this field. It has succeeded admirably, as Iran ranked seventh worldwide by 2014 for the volume of papers related to nanotechnology (Figure 15.5). Iran has also progressed rapidly for the number of papers per million inhabitants. In the past decade, 143 nanotech companies have been established in eight industries.

Despite this feat, the average citation rate has dropped since 2009 and few patents are being granted to inventors, as yet. Moreover, the number registered with the European Patent Office and US Patents and Trademark Office dropped from 27 to 12 between 2012 and 2013 after steady growth since 2008.

20. See: nanoclub.ir

Table 15.3: **Growth in Iran's science and technology parks, 2010–2013**

	2010	2011	2012	2013
Number of science and technology parks	28	31	33	33
Number of business incubators	98	113	131	146
Patents generated by science and technology parks	310	321	340	360
Knowledge-based companies established in science and technology parks	2 169	2 518	3 000	3 400
Research personnel working in science and technology parks	16 139	16 542	19 000	22 000

Source: author, based on communication with Ministry of Science, Research and Technology, 2014

A growing network of parks and incubators

Since 2010, five science and technology parks have been set up, along with 48 business incubators (Table 15.3). Whereas some parks specialize, others group a wide spectrum of companies. For instance, the Persian Gulf Science and Technology Park (also known as the Knowledge Village) was set up in 2008; it nurtures companies in all of the following fields: information, communication and electronic technology; nanotechnology; biotechnology; oil, gas and petrochemical; maritime industry; agriculture and the date palm industry; fishing industry and aquatic species; and the food industry.

A survey of about 40 firms established in science and technology parks in Iran's East Azarbaijan Province in 2010 found a correlation between the level of investment in R&D and the extent of innovation; it also revealed that, the longer SMEs had been established in the park, the more innovative they were. On the other hand, the most dynamic firms were not necessarily those with the greatest number of researchers (Fazlzadeh and Moshiri, 2010).

CONCLUSION

Science *can* grow under an embargo

We claimed in the *UNESCO Science Report 2010* that Iranian STI policy was characterized by a science push rather than a technology pull. Today, we could say that STI policy is characterized by a sanctions push rather than a science pull. The increasingly tough sanctions regime since 2011 has oriented the Iranian economy towards the domestic market. By erecting barriers to foreign imports, the sanctions have encouraged knowledge-based enterprises to localize production.

Iran reacted to the sanctions in 2014 by adopting an 'economy of resistance' – a term encompassing both economic policy and STI policy. Policy-makers are being challenged to look beyond extractive industries to the country's human capital for wealth creation, now that they have come to realize that Iran's future lies in the transition to a knowledge economy.

Iranian education policy used to focus on Iran's strength in basic sciences. This focus, together with other factors like the petrodollars windfall, had divorced science from socio-economic needs, as we saw in the *UNESCO Science Report 2010*. The deteriorating economic situation, coupled with a surge in the number of graduate students and the difficulties they encounter in finding work, has created a fertile terrain for a greater focus on applied sciences and technology. In this context, the government's limited budget is being directed towards supporting small innovative businesses, business incubators and science and technology parks, the type of enterprises which employ graduates. In parallel, the Ministry of Science, Research and Technology plans to develop more interdisciplinary university courses and a Master of Business Administration degree, in order to make university curricula more responsive to socio-economic needs.

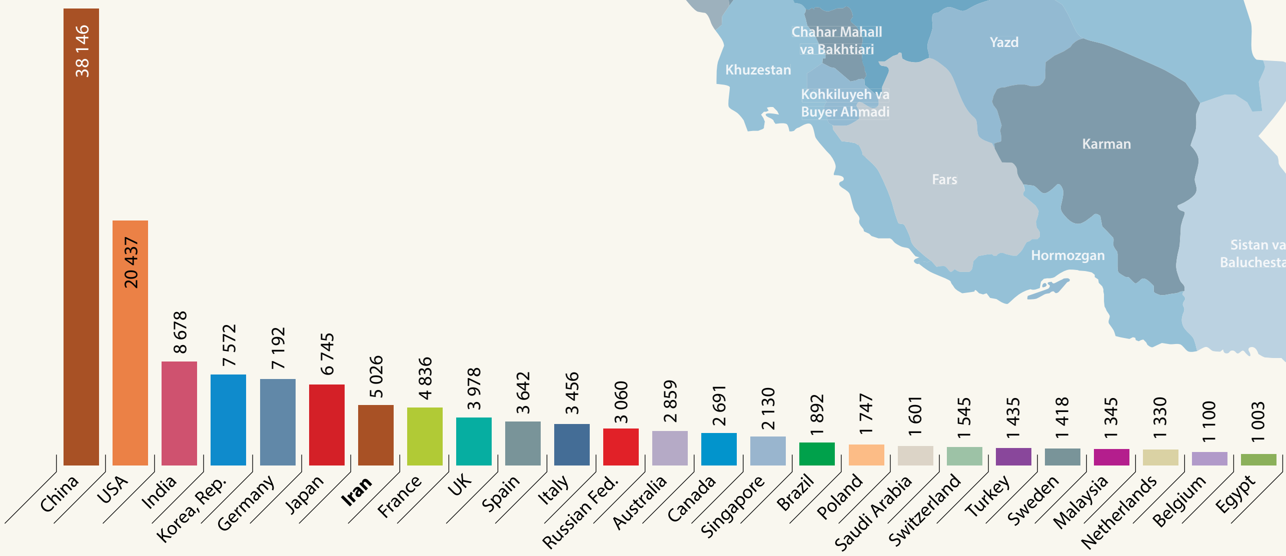
The sanctions have had one unanticipated, yet welcome effect. With the state no longer able to rely on petrodollars to oil the wheels of a sprawling administration, the government has embarked upon reform to reduce institutional costs, introduce a more disciplined budgeting system and improve science governance.

Iran's experience offers a unique perspective. More than any other factor, the growing importance of STI policy in Iran is a consequence of the tougher international sanctions. Science *can* grow under an embargo. This realization offers hope for a brighter future in Iran.

Figure 15.5: **Trends in nanotechnology in Iran**

Iran is now ranked seventh worldwide for the number of nanotech-related papers

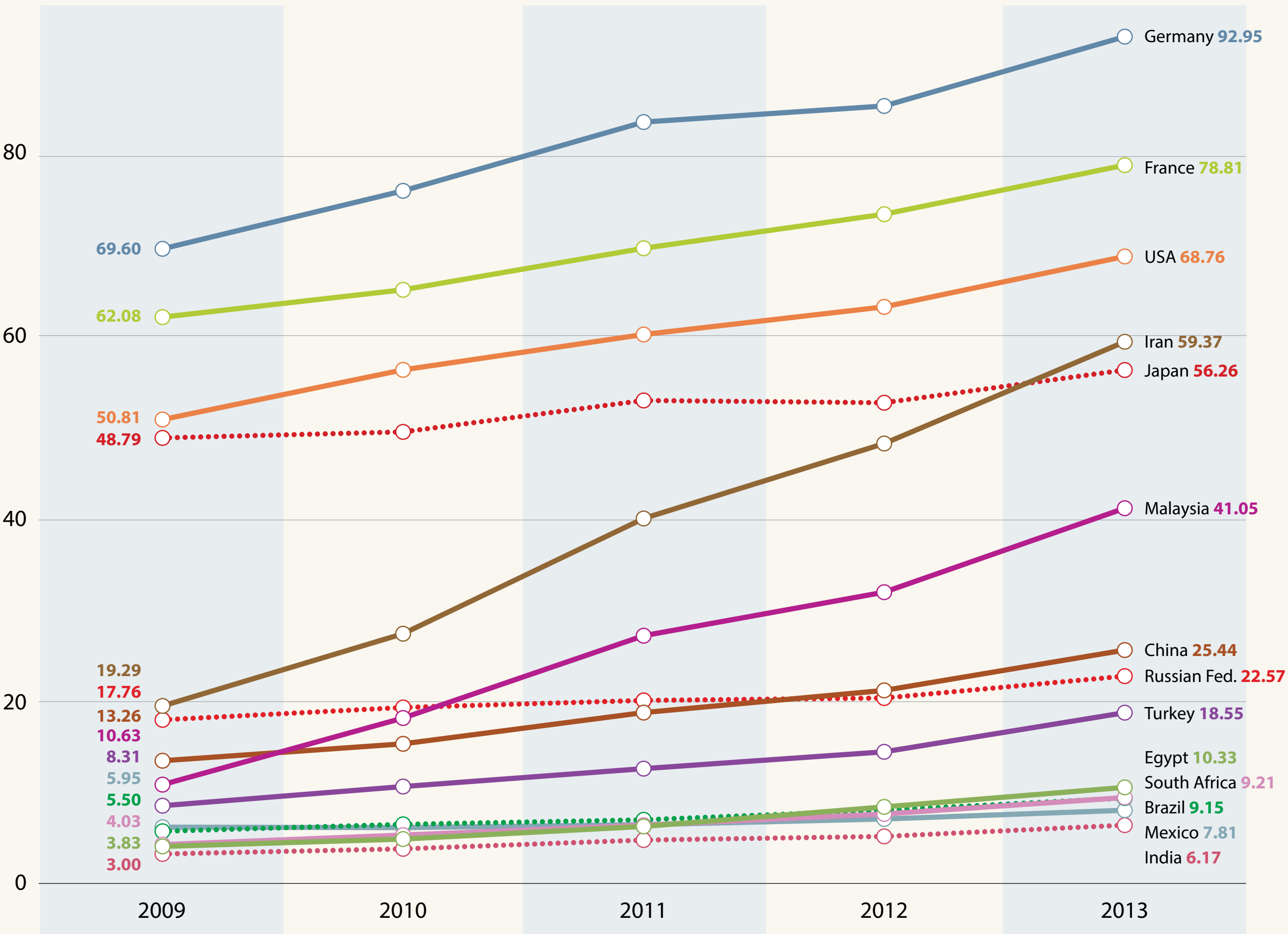
Top 25 for volume of nanotechnology-related papers, 2014



Note: The total for China does not include Chinese Taipei, which recorded 3 139 papers in this database in 2014.

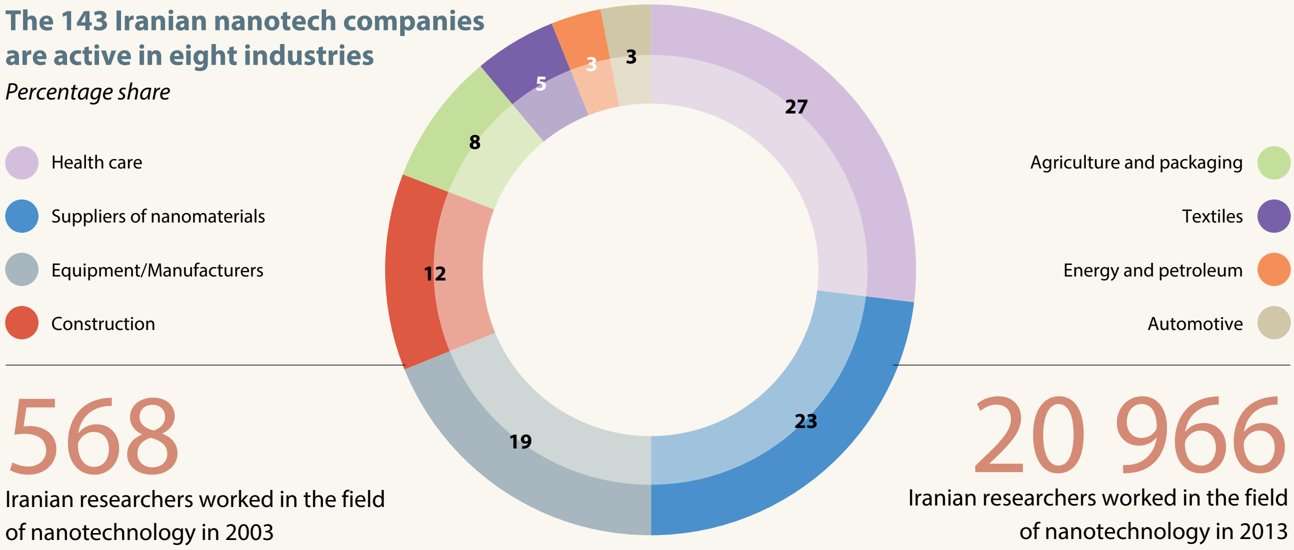
Iran performs well for the number of nanoarticles per million inhabitants

Other countries are given for comparison



The 143 Iranian nanotech companies are active in eight industries

Percentage share



568

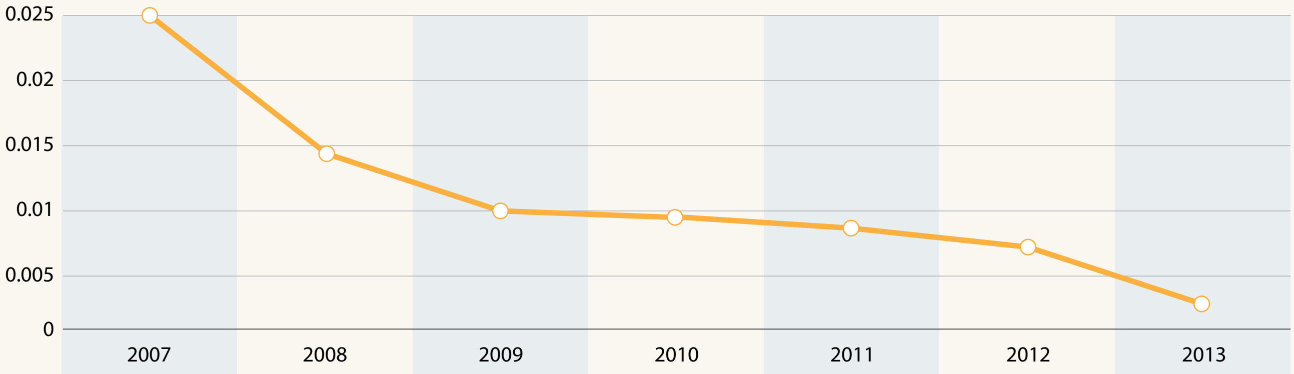
Iranian researchers worked in the field of nanotechnology in 2003

20 966

Iranian researchers worked in the field of nanotechnology in 2013

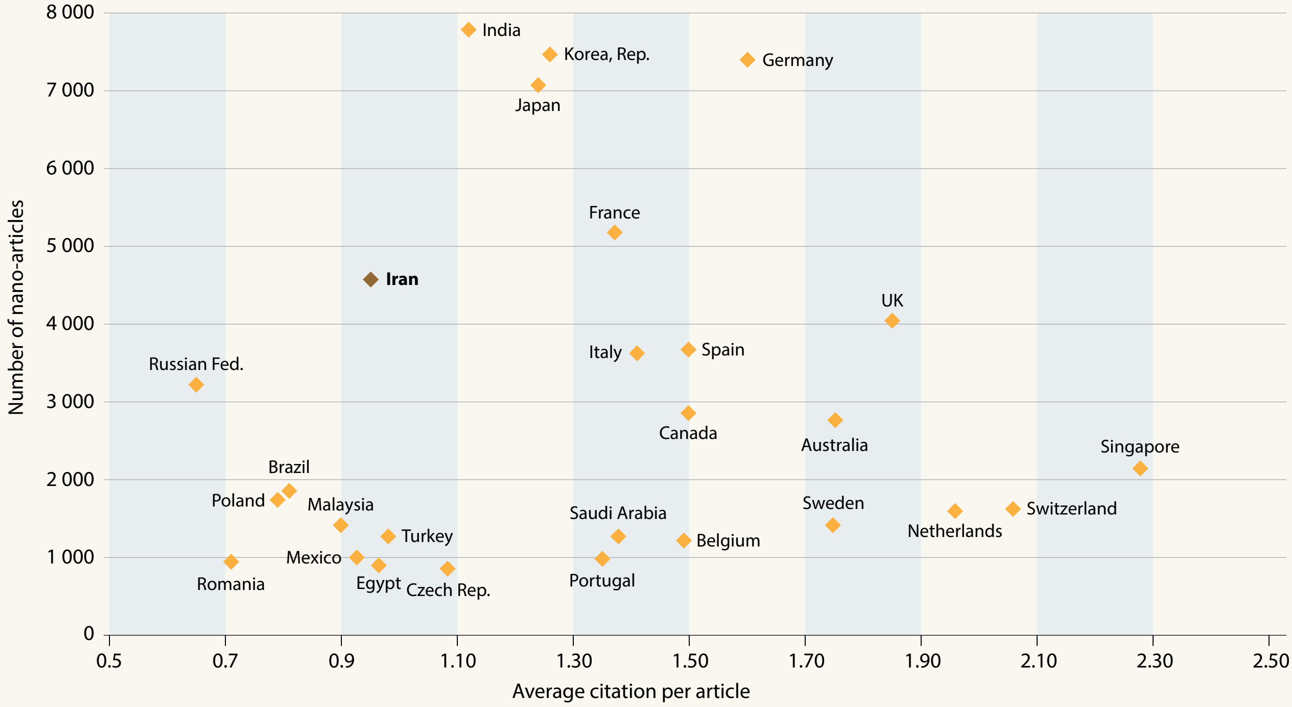
Patents are not keeping pace with growth in publications…

Number of nanotech patents from Iran registered by EPO and USPTO per 100 scientific articles



… and quality does not yet match quantity in Iran

Average citations of Iranian nanotech articles, in comparison with those of other leading countries, 2013



Source: statnano.com (January 2015), based on data from Thomson Reuters' Web of Science, Science Citation Index Expanded, and records from European Patent Office and US Patents and Trademark Office

KEY TARGETS FOR IRAN

- Raise the GERD/GDP ratio to 3% by 2015 and to 4% by 2025;
- Carry business expenditure on R&D to 50% of GERD by 2025;
- Raise the share of researchers employed by the business enterprise sector to 40% by 2025;
- Increase the number of full-time university professors per million population from 1 171 in 2013 to 2 000 in 2025;
- Raise FDI to 3% of GDP by 2015;
- Privatize 80% of state-owned firms between 2004 and 2014;
- Publish 800 scientific articles in international journals per million population by 2025, compared to 239 in 2013.

REFERENCES

Davarpanah, M. R. and H. M. Moghadam (2012) The contribution of women in Iranian scholarly publication. *Library Review,* 61(4): 261–271.

Dehghan, S. K. (2014) Iranian students blocked from UK STEM courses due to US sanctions. *The Guardian Online*, 26 June.

Fakhari H.; Soleimani D. and F. Darabi (2013) The impact of sanctions on knowledge-based companies. *Journal of Science and Technology Policy* 5(3).

Fazlzadeh, A. and M. Moshiri (2010) An investigation of innovation in small scale industries located in science parks of Iran. *International Journal of Business and Management,* 5(10): 148.

Ghaneirad, M. A.; Toloo, A. and F. Khosrokhavar (2008), Factors Motives and Challenges of Knowledge Production among Scientific Elites. *Journal of Science and Technology Policy* 1(2): 71–86.

Ghazimi R. (2012) *Iran's Economic Crisis: a Failure of Planning*. See: www.muftah.org

Ghazinoory, S.; Yazdi, F. S. and A.M. Soltani (2012) Iran and nanotechnology: a new experience of on-time entry. In: N. Aydogan-Duda (ed.) *Making It to the Forefront: Nanotechnology – a Developing Country Perspective*. Springer: New York.

Ghazinoory, S.; Divsalar, A. and A. Soofi (2009) A new definition and framework for the development of a national technology strategy: the case of nanotechnology for Iran. *Technological Forecasting and Social Change* 76(6): 835–848.

Ghorashi, A. H. and A. Rahimi (2011) Renewable and non-renewable energy status in Iran: art of know-how and technology gaps. *Renewable and Sustainable Energy Reviews,* 15(1): 729–736.

Habibi, N. (2013) *The Economic Legacy of Mahmoud Ahmadinejad*. Middle East Brief, Crown Center for Middle East Studies, June, no.74. See: www.brandeis.edu/crown/publications/meb/MEB74.pdf

Hariri N. and A. Riahi (2014) Scientific Cooperation of Iran and Developing Countries. *Journal of Science and Technology Policy* 3(3).

IMF (2014) Islamic Republic of Iran: Selected Issues Paper. Country Report 14/94. International Monetary Fund. April.

Jowkar, A.; Didegah, F. and A. Gazni (2011) The effect of funding on academic research impact: a case study of Iranian publications. *Aslib Proceedings*, 63 (6) 593–602.

Khajehpour, B. (2014a) Decoding Iran's 'resistance economy.' *Al Monitor,* 24 February. See: www.al-monitor.com

Khajehpour, B. (2014b) *Impact of External Sanctions on the Iranian Pharmaceutical Sector*. Editorial. Hand Research Foundation. See: www.handresearch.org

Leylaz, S. (2014) Iran gov't economic achievements outlined. *Iranian Republic News Agency* 2 November. See: www.irna.ir/en/News/2783131

Manteghi, M.; Hasani, A. and A.N. Boushehri (2010) Identifying the policy challenges in the national innovation system of Iran. *Journal of Science and Technology Policy* 2 (3).

Mistry, D. and B. Gopalaswamy (2012) Ballistic missiles and space launch vehicles in regional powers. *Astropolitics,* 10(2): 126–151.

Mousavian, S. H. (2012) *The Iranian Nuclear Crisis: a Memoir Paperback*. Carnegie Endowment for International Peace: USA.

Namazi, S. (2013) Sanctions and medical supply shortages in Iran. *Viewpoints,* 20.

PressTV (2012) IKCO to allocate 3% of sales to research, 29 January. See: http://presstv.com/detail/223755.html

PressTV (2008) *Iran invests $2.5b in stem cell research*. 7 November. See: www.presstv.ir

Rezaian, J. (2013) Iran's automakers stalled by sanctions. *Washington Post,* 14 October 2013.

Riahi, A; Ghaneei, R.M.A. and E. Ahmadi (2013) Iran's Scientific Interaction and Commutations with the G8 Countries. Skype Presentation. Proceedings of 9th International Conference on Webometrics Informetrics and Scientometrics and 14th COLLNET Meeting. Tartu, Estonia.

Tehran Times (2013) 14 000 foreign students studying in Iran. *Tehran Times*, 10 July, vol. 122 237.

UIS (2014) *Higher Education in Asia: Expanding Out, Expanding Up*. UNESCO Institute for Statistics: Montreal (Canada).

Williams, A. (2008) Iran opens its first solar power plant. *Clean Technica.* See: www.cleantechnica.com.

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Israel needs to prepare for tomorrow's science-based industries.

Daphne Getz and **Zehev Tadmor**

A miniaturized device developed in Professor Moshe Shoham's robotics laboratory at the Technion Institute of Technology in Haifa. Based on micro-electro-mechanical systems technology, the tiny robot can theoretically be guided inside the body via an external controller to perform a variety of medical tasks in a much less invasive way than currently possible.
Photo: © Technion Institute of Technology

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Daphne Getz and Zehev Tadmor

INTRODUCTION

A geopolitical landscape in rapid mutation

Since the Arab Spring of 2011, the political, social, religious and military realities of the Middle East have been profoundly remodelled through regime change, civil war and the emergence of opportunistic politico-military sects like Da'esh (see Chapter 17). In Israel's wider neighbourhood, relations between the Western powers and Iran could be at a turning point (see p. 387). In the past five years, there has been no tangible progress towards a peaceful solution to the Israeli–Palestinian conflict, a state of affairs which may have negative repercussions for Israel's international and regional collaboration, as well as its progress in STI. Despite the tensions, there are instances of academic collaboration with neighbouring Arab countries (see p. 427).

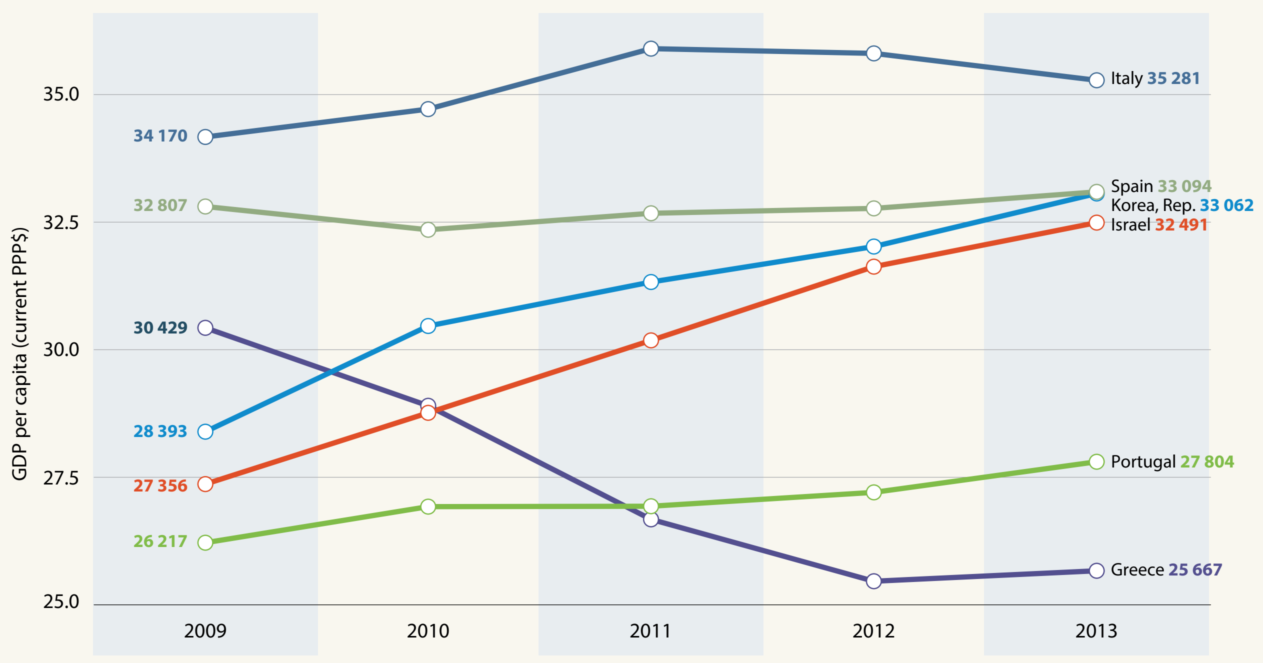
At home, the political leadership was renewed in the March 2015 elections. In order to obtain a ruling majority in the Knesset – the Israeli parliament –, the re-elected Prime Minister Binyamin Netanyahu has formed a coalition government with *Kulanu* (10 seats), *United Torah Judaism* (6 seats), *Shas* (7 seats) and *Bayit Yehudi* (8 seats), which, together with his own *Likud* party (30 seats), gives him a ruling majority of 61 seats in the Knesset. For the first time, a coalition of Arab–Israeli parties has obtained 14 out of the 120 seats in the new Knesset, making it the third-largest bloc in Israel's political landscape after the *Likud* and the *Zionist Camp* (Labour) party led by Isaac Herzog (24 seats). Arab Israelis are thus in a unique position to influence the legislative process, including as concerns issues related to STI.

No lasting impact of global financial crisis

The Israeli economy grew by 28% between 2009 and 2013 to PPP$ 261.9 billion and GDP per capita progressed by 19% (Figure 16.1). This impressive performance reflects the dominance of the medium- and high-tech sector, which constitutes the country's main growth engine and contributes 46% of Israeli exports (2012). This sector is dominated by information and communication technologies (ICTs) and high-tech services. Given its reliance on international markets and venture capital, the Israeli business enterprise sector was fairly exposed to the global financial crisis of 2008–2009. The Israeli economy has sailed through the crisis mainly due to a balanced fiscal policy and conservative measures in the real-estate market. On the R&D front, government subsidies[1] introduced in 2009 have helped high-tech firms to weather the storm, leaving them relatively unscathed.

1. There was a 12% increase in funding from government sources and international funds.

Figure 16.1: **GDP per capita in Israel, 2009–2013**
In thousands of current PPP$, other countries are given for comparison



Source: World Bank's World Development Indicators, May 2015

Data released by the Central Bureau of Statistics in 2011 reveal that the manufacturing sector cut back its R&D expenditure by 5% and the services sector by 6% between 2008 and 2009. Each of these sectors performed about 30% of R&D in 2008 (UNESCO, 2012). As the business enterprise sector performs 83–84% of gross domestic expenditure on R&D (GERD), the cutbacks in the business enterprise sector caused the GERD/GDP ratio to falter in 2010 (3.96% of GDP). Israel has nevertheless managed to hold on to its place as world leader for R&D intensity, even if it is now being trailed by the Republic of Korea (Figure 16.2).

OECD membership has boosted investor confidence

Israel's admission to the Organisation for Economic Co-operation and Development (OECD) in 2010 has strengthened investors' confidence in the Israeli economy. Since its admission to this exclusive club, Israel has further opened up its economy to international trade and investment by lowering tariffs, adopting international standards and improving the domestic regulatory environment for business[2]. Israel now meets the OECD's policy framework for market openness, including as concerns efficient regulation and intellectual property. Israel's regulatory reforms have already led to significant growth in the influx of foreign direct investment (FDI) [OECD, 2014]. This inflow of FDI (Table 16.1) has given the Israeli high-tech sector greater access to much-needed capital which, in turn, has had a positive effect on Israeli GDP, which rose from PPP$ 204 849 million to PPP$ 261 858 million (in current prices) between 2009 and 2013.

2. See: www.oecd.org/israel/48262991.pdf

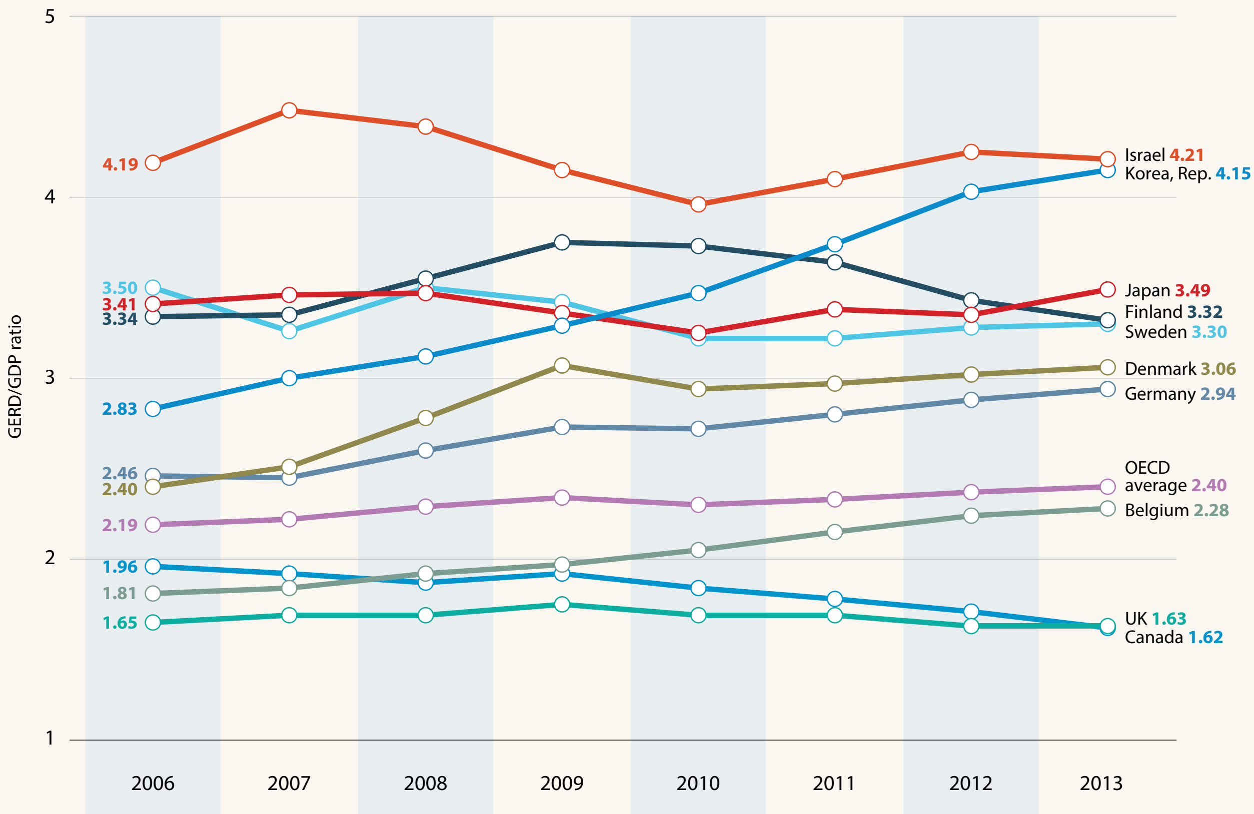
Table 16.1: **FDI inflows to Israel and outflows, 2009–2013**

	FDI inflow	FDI outflow	FDI inflow	FDI outflow
	In current US$ millions		Share of GDP (%)	
2009	4 438	1 695	2.2	0.8
2010	5 510	9 088	2.5	4.1
2011	9 095	9 165	3.9	3.9
2012	8 055	3 257	3.2	1.3
2013	11 804	4 670	4.5	1.8

Source: Central Bureau of Statistics

Figure 16.2: **Trends in Israel's GERD/GDP ratio, 2006–2013**

Other countries and regions are given for comparison



Note: The data for Israel exclude defence R&D.

Source: Getz *et al.* (2013), updated

Israel's binary economy threatens social equity and lasting growth

Israel's 'binary economy' consists of a relatively small, yet world-class high-tech sector which serves as the 'locomotive' of the economy, on the one hand, and the much larger but less efficient traditional industrial and services sectors, on the other hand. The economic contribution of the flourishing high-tech sector does not always spill over into other sectors of the economy.

Over time, this 'binary economic structure' has led to a well-paid labour force living at the 'core' of the country, namely the Tel Aviv metropolitan area, and a poorly paid labour force living primarily on the periphery. The growing socio-economic gap that has resulted from the structure of the economy and the concentration of wealth among the upper 1% is having a destabilizing effect on society (Brodet, 2008).

This duality is underpinned by a low rate of labour force participation, compared to other OECD economies, although the rate did rise from 59.8% to 63.7% between 2003 and 2013, thanks to improvements in the level of education (Fatal, 2013): as of 2014, 55% of the Israeli labour force had 13 or more years of schooling and 30% had studied for 16 years or more (CBS, 2014). The low rate of labour force participation in the general population stems mainly from low levels of participation by ultra-orthodox men and Arab women. The unemployment rate is also higher among Arabs than Jews, particularly among Arab women (Table 16.2).

Table 16.2: **Characteristics of Israel's civilian labour force, 2013**

	Total adult population*	Civilian labour force ('000s)	Civilian labour force (%)	Share of unemployed (%)
Total	**5 775.1**	**3 677.8**	**64**	**6.2**
Jewish	4 549.5	3 061.8	67	5.8
Arabs	1 057.2	482.8	46	9.4
Males	**2 818.3**	**1 955.9**	**69**	**6.2**
Jewish	2 211.9	1 549.8	70	5.8
Arab	530.8	344.4	65	8.2
Females	**2 956.7**	**1 722.0**	**58**	**6.2**
Jewish	2 337.6	1 512.0	65	5.8
Arab	526.4	138.4	26	12.4

Source: Central Bureau of Statistics

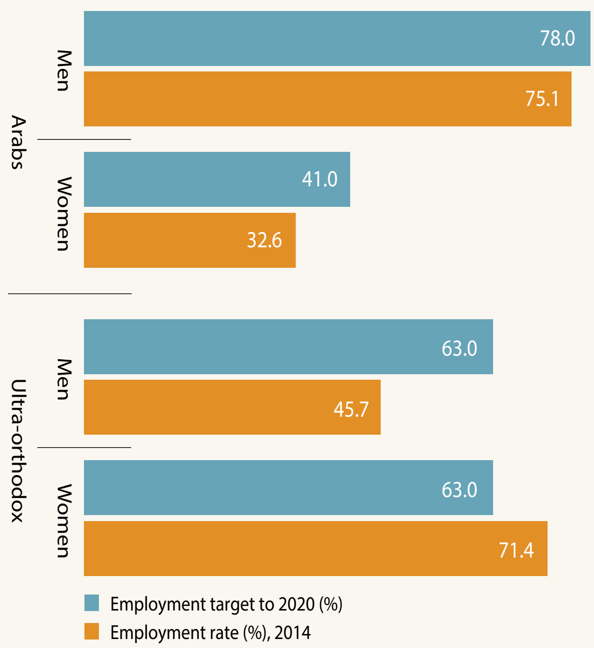
The latter phenomenon is attributable to the insufficient integration of Arab citizens into wider Israeli society, partly owing to their geographic remoteness and inadequate infrastructure; a lack of the social networks needed to find suitable employment; and discriminatory practices in certain segments of the economy.

To drive sustainable and long-lasting economic growth, it will be crucial for Israel to integrate its minority populations into the labour market. This realization prompted the government to fix a series of targets in December 2014 for raising the participation rate of minorities (Figure 16.3).

The country's transition from a semi-socialist economy in the 1980s to a free market economy has been accompanied by a rise in inequality, as illustrated by the steady rise in the Gini index (see the glossary, p. 738). As of 2011, nearly 42% of gross monthly income in Israel was concentrated in households which made up 20% of the population (the 2 top deciles). The Israeli middle class, occupying deciles 4–7, accounted for only 33% of gross income. Inequality after taxes and transfer payments has increased even more sharply, as the government has steadily reduced welfare benefits since 2003 (UNESCO, forthcoming).

The duality of the Israeli economy is also reflected in the low labour productivity, calculated as GDP per working hour. Israel

Figure 16.3: **Employment targets to 2020 for Israeli minorities**



Note: The employment targets were fixed in 2010 by a special committee charged with examining Israel's Employment Policy. The target for the employment rate for ultra-orthodox women was reached before 2014.

Source: General Accountant (2014) *Managing the Fiscal Policy Goals*. Ministry of Finance (in Hebrew) ranks 26th out of 34 OECD countries for this indicator and has been gradually slipping in the ranking since the 1970s (Ben David, 2014), even though it boasts some of the world's leading universities and cutting-edge high-tech firms.

Labour productivity in Israel varies strongly in technological intensity. In medium- and high-tech industries, labour productivity is significantly higher than in other manufacturing industries. In the services sector, the highest levels of production per employee are to be found in knowledge- and technology-intensive industries, such as the computer industry, R&D services and communications. The medium- and high-tech manufacturing sectors account for about 13% of GDP and 7% of total employment, even though their output contributes 46% of industrial exports, as mentioned earlier. The main industries in the manufacturing sector are chemical and pharmaceutical products, computers, electronics and optical products (Getz *et al.*, 2013).

Those industrial and services sectors that are classified as using low technologies or medium–low technologies account for the greater part of production and employment in the business sector, yet they suffer from low productivity per employee (Figure 16.4). The key to sustainable, long-term economic growth will lie in improving productivity in traditional industries and in the services sector (Flug, 2015). This can be achieved by giving firms incentives to innovate, assimilate advanced technologies, implement the requisite organizational changes and adopt new business models to raise the share of exports in their output (Brodet, 2008).

The government hopes to raise industrial-level productivity – the value added by each employee – from PPP$ 63 996 in 2014 to PPP$ 82 247 by 2020.

TRENDS IN R&D

Still the world leader for R&D intensity

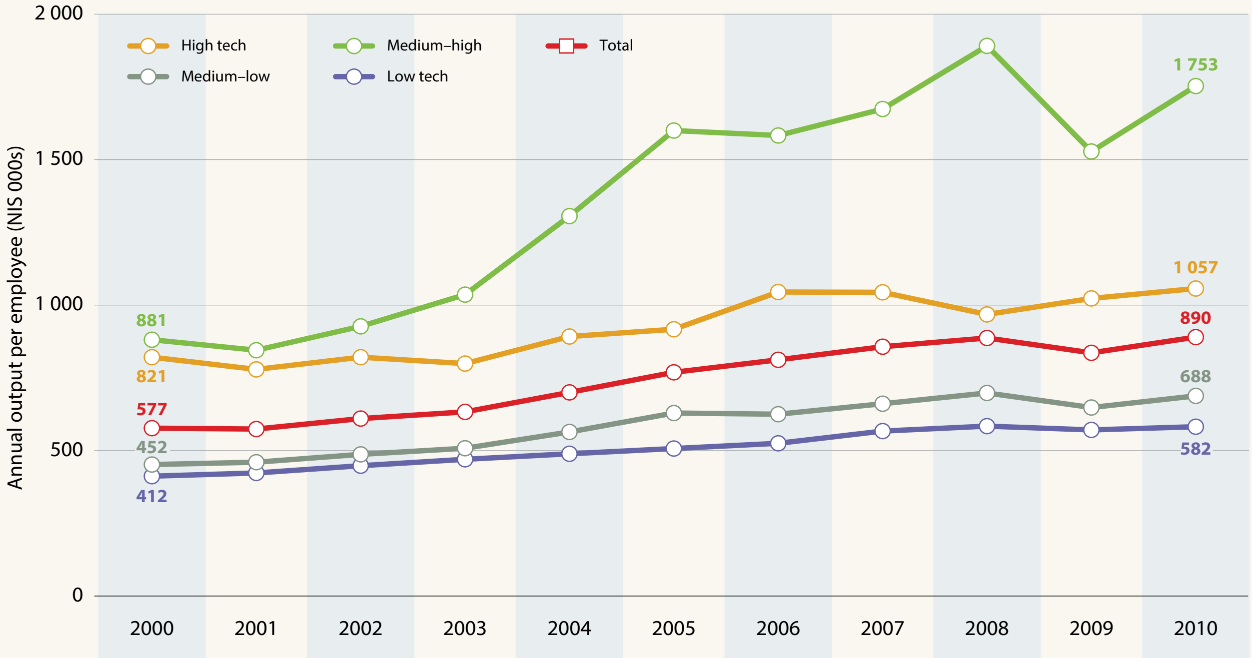
Israel tops the world for R&D intensity, reflecting the importance of research and innovation for the economy. Since 2008, however, Israel's R&D intensity has weakened somewhat (4.2% in 2014), even as this ratio has experienced impressive growth in the Republic of Korea, Denmark, Germany and Belgium (Figure 16.2) [Getz *et al.*, 2013]. Business expenditure on R&D (BERD)[3] continues to account for ~84% of GERD, or 3.49% of GDP. The share of higher education in GERD has decreased since 2003 from 0.69% of GDP to 0.59% of GDP (2013). Despite this drop, Israel ranks 8th among OECD countries for this indicator.

The lion's share of GERD (45.6%) in Israel is financed by foreign companies (Figure 16.5), reflecting the large scale of activity by foreign multinational companies and R&D centres in the country.

The share of foreign funding in university-performed R&D is also quite significant (21.8%). By the end of 2014, Israel had received € 875.6 million from the European Union's (EU's) Seventh Framework Programme for Research and Innovation (2007–2013),

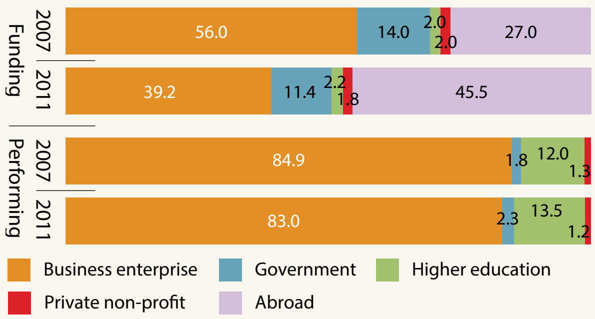
3. refers to GERD performed by the business enterprise sector

Figure 16.4: **Annual output per employee in Israel, 2000–2010**
In thousands of NIS, breakdown by technological intensity



Source: Central Bureau of Statistics

Figure 16.5: **GERD in Israel by funding and performing sectors, 2007 and 2011 (%)**



Note: Excluding defence R&D.

Source: Central Bureau of Statistics

70% of which had gone to universities. Its successor, Horizon 2020 (2014–2020), has been endowed with nearly € 80 billion in funding, making it the EU's most ambitious research and innovation programme ever. As of February 2015, Israel had received € 119.8 million from the Horizon 2020 programme.

In 2013, more than half (51.8%) of government spending was allocated to university research and an additional 29.9% to the development of industrial technologies. R&D expenditure on health and the environment has doubled in absolute terms in the past decade but still accounts for less than 1% of total government GERD (Figure 16.6). Israel is unique among OECD countries in its distribution of government support by objectives. Israel ranks at the bottom in government support of research in health care, environmental quality and infrastructure development.

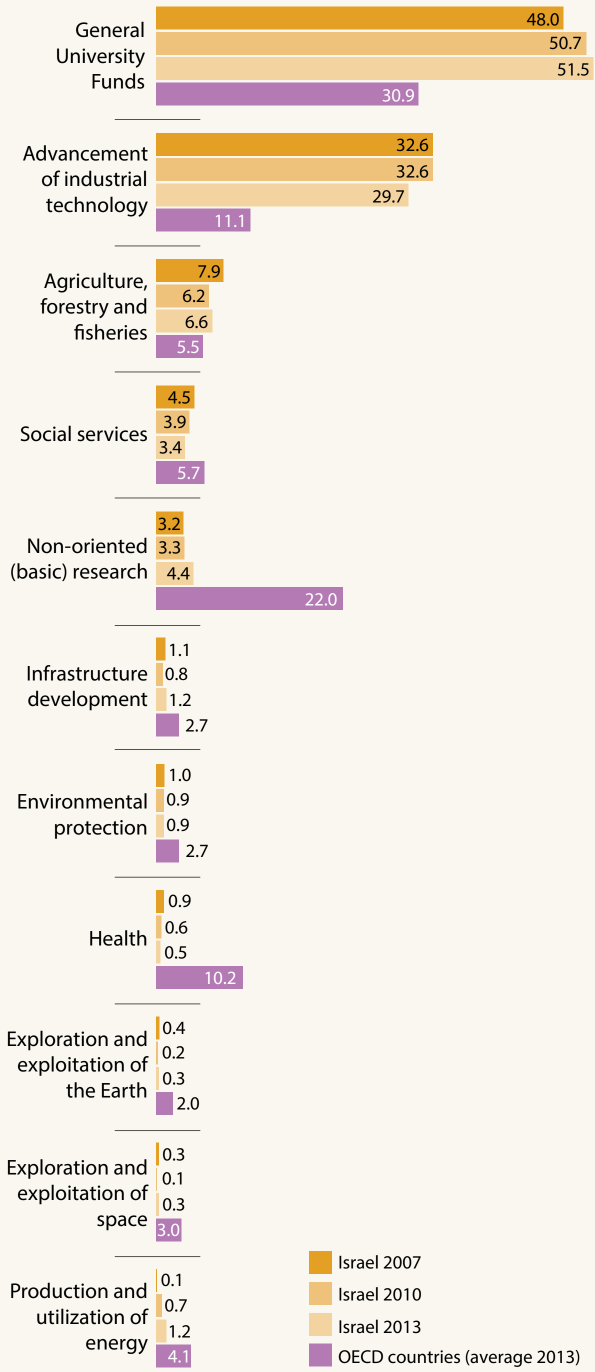
University research in Israel is largely grounded in basic research, even though it also engages in applied research and partnerships with industry. The increase in General University Funds and non-oriented research should thus provide a significant boost to basic research in Israel, which only accounted for 13% of research in 2013, compared to 16% in 2006 (Figure 16.7).

In 2012, there were 77 282 full-time equivalent (FTE) researchers, 82% of whom had acquired an academic education, 10% of whom were practical engineers and technicians and 8% of whom held other qualifications. Eight out of ten (83.8%) were employed in the business sector, 1.1% in the government sector, 14.4 % in the higher education sector and 0.7% in non-profit institutions.

In 2011, 28% of senior academic staff were women, up by 5% over the previous decade (from 25% in 2005) [Figure 16.8]. Although the representation of women has increased, it remains very low in engineering (14%), physical sciences (11%), mathematics and computer sciences (10%) relative to education (52%) and paramedical occupations (63%).

Figure 16.6: **Israeli government outlay for R&D by major socio-economic objective, 2007, 2010 and 2013 (%)**

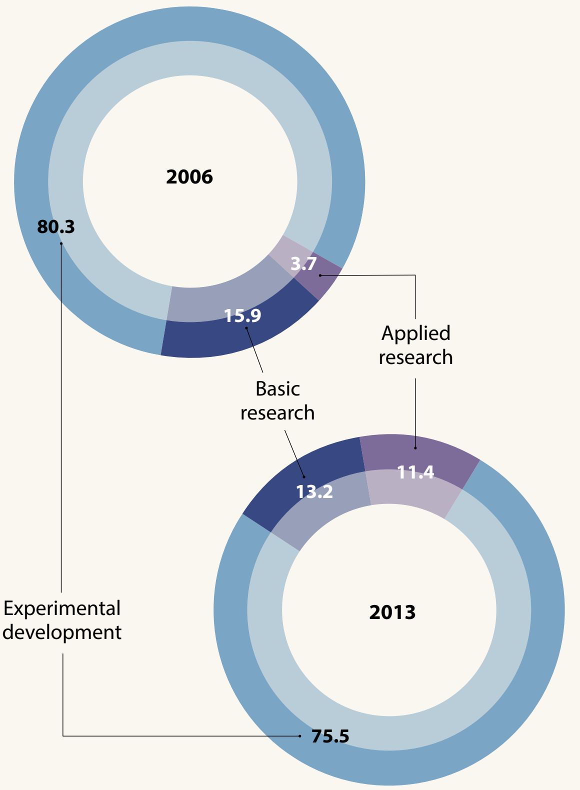
The OECD is given for comparison



Note: The data for Israel do not include defence R&D. The data for Israel diverge strongly from those for the OECD in two categories: health and non-oriented research. The low percentage in health can be explained by the fact that, in Israel, R&D in hospitals is assigned to the business sector and not to the government sector. The high percentage in non-oriented research for the OECD (22%) and the low percentage for Israel (4.4%) can be explained by the fact that the OECD indicator encompasses a variety of subjects.

Source: adapted from Getz *et al.* (2013)

Figure 16.7: **GERD in Israel by type of research, 2006 and 2013 (%)**



Note: The data do not include defence R&D.

Source: UNESCO Institute for Statistics, June 2015

TRENDS IN STI GOVERNANCE

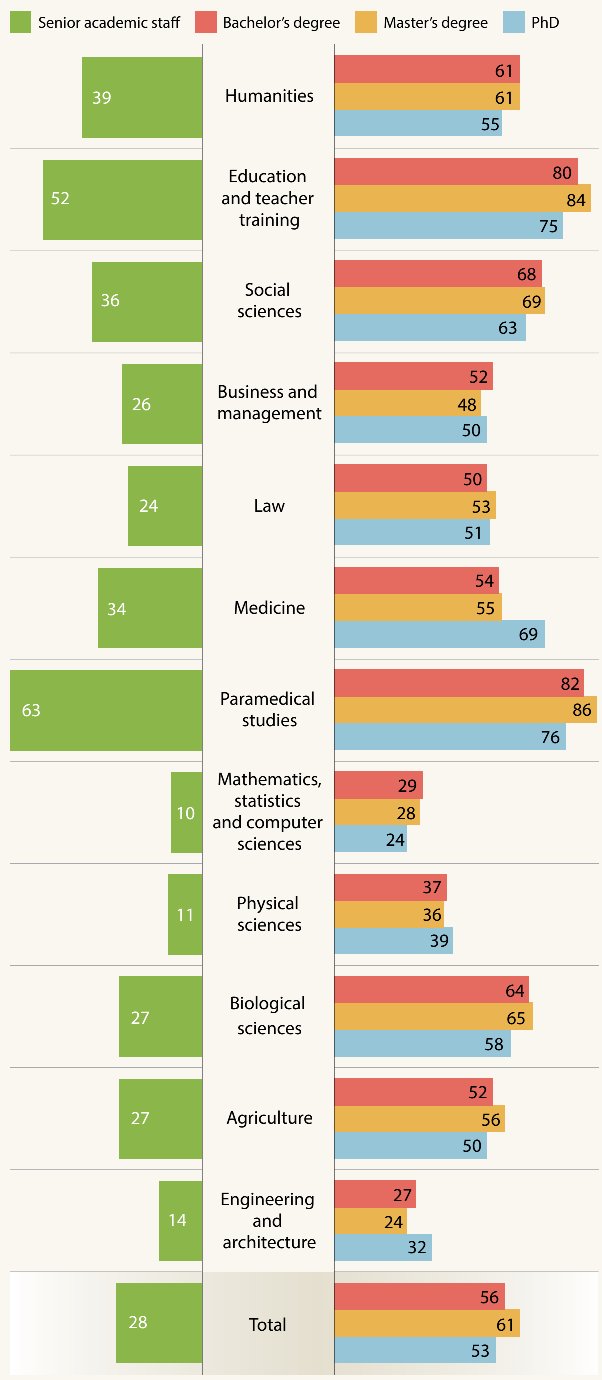
A six-year plan to revamp higher education

Israel's higher education system is regulated by the Council for Higher Education and its Planning and Budgeting Committee. The Israeli higher education system operates under a multi-year plan agreed upon by the Planning and Budgeting Committee (PBC) and the Ministry of Finance. Each plan determines policy objectives and, accordingly, the budgets to be allocated in order to achieve these objectives. The annual government allocation to universities totalled about US$ 1 750 million in 2015, providing 50–75% of their operating budgets. Much of the remainder of their operating budget (15–20%) comes from annual student tuition fees, which are uniform at about US$ 2 750 per year.

The *Sixth Higher Education Plan* (2011–2016) makes provision for a 30% rise in the Council for Higher Education's budget. The *Sixth Plan* changes the budgeting model of the PBC by placing greater emphasis on excellence in research, along with quantitative measures for the number of students. Under this model, 75% of the committee's budget (NIS 7 billion over six years) is being allocated to institutions offering higher education.

In the 2012/2013 academic year, there were 4 066 faculty members. The targets fixed by the PBC for faculty recruitment are ambitious: universities are to recruit another 1 600 senior faculty within the six-year period – about half of whom will occupy new positions and half will replace faculty expected to retire. This will constitute a net increase of more than 15%

Figure 16.8: **Share of women among Israeli university students (2013) and senior academic staff (2011) (%)**



Source: Central Bureau of Statistics

in university faculty. In colleges, another 400 new positions are to be created, entailing a 25% net increase. The new faculty will be hired via the institutions' regular recruitment channels, some in specific research areas, through the Israeli Centres of Research Excellence programme described below (Box 16.1).

The increase in faculty numbers will also reduce the student-to-faculty ratio, the target being to achieve a ratio of 21.5 university students to every faculty member, compared to 24.3 at present, and 35 students for every faculty member in colleges, compared to 38 at present.

This massive increase in the number of faculty positions, alongside the upgrading of research and teaching infrastructure and the increase in competitive research funds, should help Israel to staunch brain drain by enabling the best Israeli researchers at home and abroad to conduct their academic work in Israel, if they so wish, at institutions offering the highest academic standards.

The new budgeting scheme described above is mainly concerned with the human and research infrastructure in universities. Most of the physical development (e.g. buildings) and scientific infrastructure (e.g. laboratories and expensive equipment) of universities comes from philanthropic donations, primarily from the American Jewish community (CHE, 2014). This latter source of funding has greatly compensated for the lack of sufficient government funding for universities up until now but it is expected to diminish significantly in the years to come. Unless the government invests more in research infrastructure, Israel's universities will be ill-equipped and insufficiently funded to meet the challenges of the 21st century. This is very worrying.

Renewed interest in academic R&D

The *Sixth Higher Education Plan* launched the Israeli Centres of Research Excellence (I-CORE) programme in 2011 (Box 16.1). This is perhaps the strongest indication of a reversal in government policy, as it reflects a renewed interest in funding academic R&D. This novel programme envisions the establishment of cross-institutional clusters of top researchers in specific fields and returning young Israeli scientists from abroad, with each centre being endowed with state-of-the-art research infrastructure. The *Sixth Plan* invests NIS 300 million over six years in upgrading and renovating academic infrastructure and research facilities.

Although Israel does not have an 'umbrella type' STI policy for optimizing priorities and allocating resources, it does implement, *de facto*, an undeclared set of best practices combining bottom-up and top-down processes via government offices, such as those of the Chief Scientist or the Minister of Science, Technology and Space, as well as *ad hoc* organizations like the Telem forum (see p. 420). The procedure for selecting research projects for the Israeli centres of research excellence is one example of this bottom-up process (Box 16.1).

Box 16.1: **Israeli Centres of Research Excellence**

The Israeli Centres of Research Excellence (I-CORE) programme was launched in October 2011. It is run jointly by the Council for Higher Education's Planning and Budgeting Committee and the Israel Science Foundation.

So far, 16 centres have been established in two waves across a wide spectrum of research areas: six specialize in life sciences and medicine, five in the exact sciences and engineering, three in social sciences and law and two in humanities. Each centre of excellence has been selected via a peer review process conducted by the Israel Science Foundation. By May 2014, around 60 young researchers had been absorbed into these centres, many of whom had previously worked abroad.

The research topics of each centre are selected through a broad bottom-up process comprising of consultations with the Israeli academic community, in order to ensure that they reflect the genuine priorities and scientific interests of Israeli researchers.

I-CORE is funded by the Council for Higher Education, the host institutions and strategic business partners, with a total budget of NIS 1.35 billion (US$ 365 million).

The original goal was to set up 30 centres of research excellence in Israel by 2016. However, the establishment of the remaining 14 centres has provisionally been shelved, for lack of sufficient external capital.

In 2013–2014, the Planning and Budgeting Committee's budget for the entire I-CORE programme amounted to NIS 87.9 million, equivalent to about 1% of the total for higher education that year. This budget appears to be insufficient to create the critical mass of researchers in various academic fields and thus falls short of the programme's objective. The level of government support for the centres of excellence has grown each year since 2011 as new centres have been established and is expected to reach NIS 93.6 million by 2015–2016 before dropping to 33.7 million in 2017–2018. According to the funding model, government support should represent one-third of all funding, another third being funded by the participating universities and the remaining third by donors or investors.

Source: CHE (2014)

A shortage of professionals looms

During the 2012/2013 academic year, 34% of bachelor's degrees were obtained in S&T fields in Israel. This compares well with the proportion in the Republic of Korea (40%) and most Western countries (about 30% on average). The proportion of Israeli graduates in S&T fields was slightly lower at the master's level (27%) but dominated at PhD level (56%).

There is a visible ageing of scientists and engineers in some fields. For instance, about three-quarters of researchers in the physical sciences are over the age of 50 and the proportion is even higher for practical engineers and technicians. The shortage of professional staff will be a major handicap for the national innovation system in the coming years, as the growing demand for engineers and technical professionals begins to outpace supply.

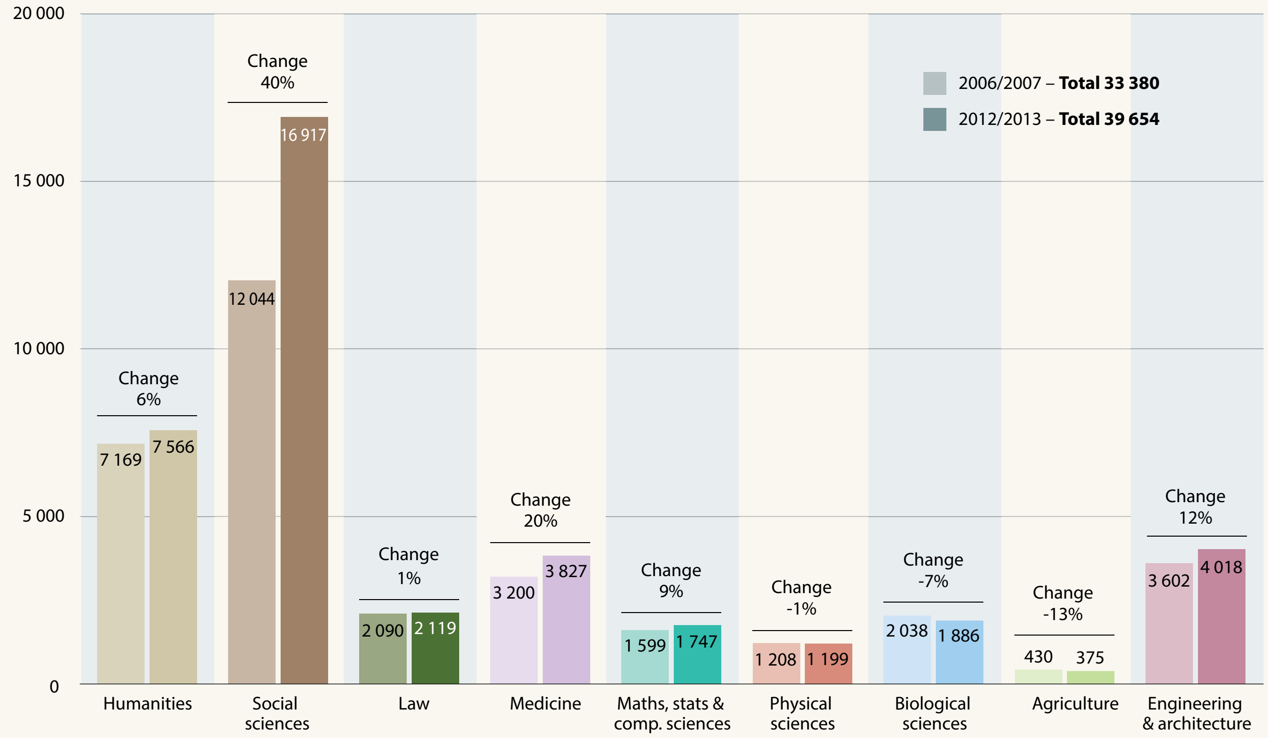
Israel has offered virtually universal access to its universities and academic colleges since the wave of Jewish immigration from the former Soviet Union in the 1990s prompted the establishment of numerous tertiary institutions to absorb the additional demand (CHE, 2014). However, the Arab and ultra-orthodox minorities still attend university in insufficient numbers. The *Sixth Higher Education Plan* places emphasis on encouraging minority groups to enrol in higher education. Two years after the *Mahar* programme was implemented in late 2012 for the ultra-orthodox population, student enrolment had grown by 1 400. Twelve new programmes for ultra-orthodox students have since been established, three of them on university campuses. Meanwhile, the Pluralism and Equal Opportunity in Higher Education programme addresses the barriers to integration of the Arab minority in the higher education system. Its scope ranges from providing secondary-school guidance through preparation for academic studies to offering students comprehensive support in their first year of study, a stage normally characterized by a high drop-out rate. The programme renews the *Ma'of* fund supporting outstanding young Arab faculty members. Since the introduction of this programme in 1995, the *Ma'of* fund has opened tenure track opportunities for nearly 100 Arab lecturers, who act as role models for younger Arab students embarking on their own academic careers.

Living on the fruits of the past?

One of the main criticisms of the current state of the higher education system is that Israel is living on the 'fruits of the past', that is to say, on the heavy investment made in primary, secondary and tertiary education during the 1950s, 1960s and 1970s (Frenkel and Leck, 2006). Between 2007 and 2013, the number of graduates in physical sciences, biological sciences and agriculture dropped, even though the total number of university graduates progressed by 19% (to 39 654) [Figure 16.9].

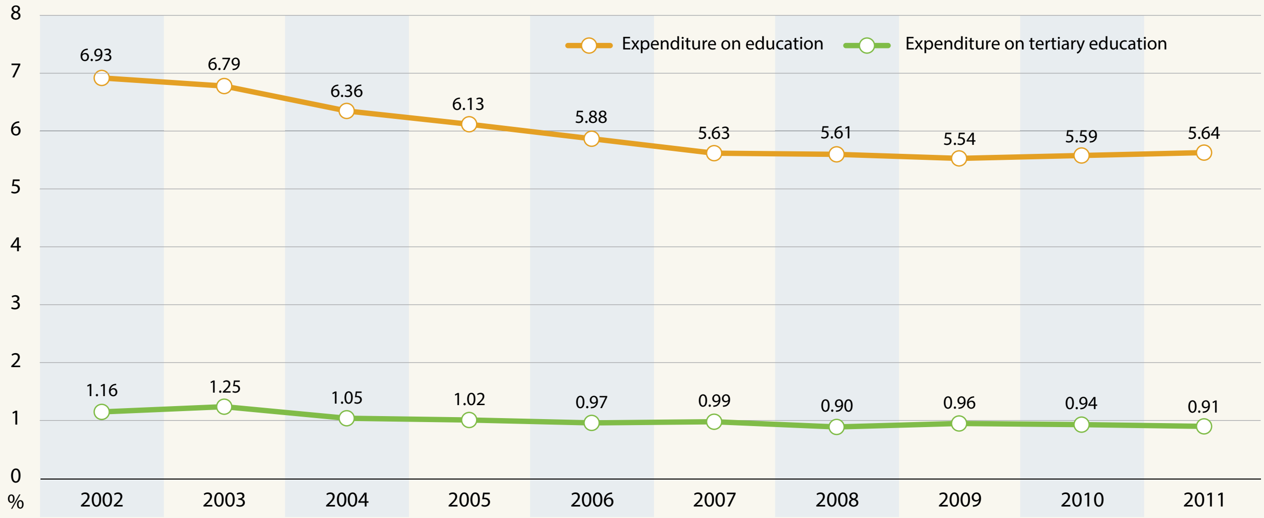
Recent data reveal that Israeli educational achievements in the core curricular subjects of mathematics and science

Figure 16.9: **University graduates in Israel, by field of study, 2006/2007 and 2012/2013**



Source: Central Bureau of Statistics

Figure 16.10: **Education spending in Israel as a share of GDP, 2002–2011 (%)**



Source: UNESCO Institute for Statistics, April 2015

are low in comparison to other OECD countries, as revealed by the exam results of Israeli 15-year olds in the OECD's Programme for International Student Assessment. Public spending on primary education has also fallen below the OECD average. The public education budget accounted for 6.9% of GDP in 2002 but only 5.6% in 2011. The share of this budget going to tertiary education has remained stable at 16–18% but, as a share of GDP, has passed under the bar of 1% (Figure 16.10). There is concern at the deteriorating quality of teachers at all levels of education and the lack of stringent demands on students to strive for excellence.

Research universities: the backbone of higher education

Seven research universities around the country form the 'backbone' of Israel's higher education system: the Hebrew University of Jerusalem, Technion – Israel Institute of Technology, Tel- Aviv University, Weizmann Institute of Science, Bar-Ilan University, University of Haifa and Ben Gurion University of the Negev.

The first six ranked among the world's top 500 universities[4] in 2014 in the Shanghai Ranking[5]. These six also ranked in the top 200 World Universities in Computer Science[6] for the same year. Three Israeli research universities rank among the top 75 in mathematics and four among the top 200 in physics and chemistry.

Over the 2007–2014 period, Israeli projects benefiting from the European Research Council's Starting Grants (see Box 9.1) recorded a success rate of 17.6% for 142 funded projects, placing Israel second after Switzerland. During the years 2008–2013, Israel ranked ninth for the European Research Council's Advanced Grants (85 funded projects), reflecting a 13.6% success rate. Since 2009, two Israeli academics have won the Nobel Prize: Professor Ada E. Yonath in 2009 for her studies on the structure and function of the ribosome and Professor Dan Shechtman in 2011 for his discovery of quasicrystals in 1984. This brings the total number of Israelis who have won the Nobel Prize in one of the sciences to eight.

The volume of publications is stagnating

The number of Israeli publications has stagnated over the past decade. Consequently, the number of Israeli publications per million inhabitants has also declined: between 2008 and 2013, it dropped from 1 488 to 1 431; this trend reflects a relative constancy in scholarly output in the face of relatively high population growth (1.1% in 2014) for a developed country and near-zero growth in the number of FTE researchers in universities.

Israeli publications have a high citation rate and a high share of papers count among the 10% most-cited (Figure 16.11). Also of note is that the share of papers with foreign co-authors is almost twice the OECD average, which is typical of small countries with developed science systems. Israeli scientists collaborate mostly with the USA and EU but there has been strong growth in recent years in collaboration with China, India, the Republic of Korea and Singapore.

Between 2005 and 2014, Israeli scientific output was particularly high in life sciences (Figure 16.11). Israeli universities do particularly well in computer science but publications in this field tend to appear mostly in conference proceedings, which are not included in the Web of Science.

4. The Hebrew University of Jerusalem and the Technion figured among the top 100, Tel Aviv University and the Weizmann Institute among the top 200.

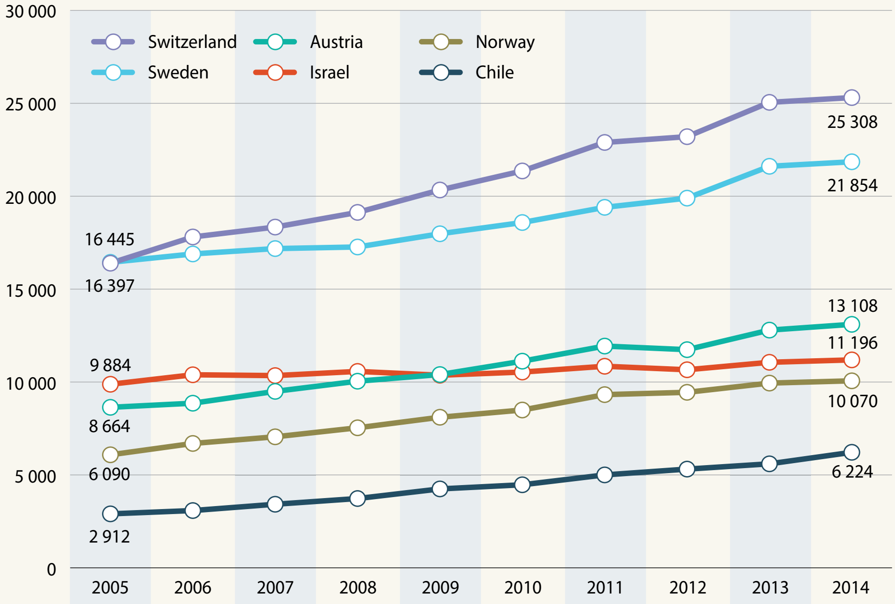
5. Shanghai Academic Ranking of World Universities, 2014

6. The Technion and Tel Aviv University ranked among the top 20, the Hebrew University and Weizmann Institute among the top 75.

Figure 16.11: **Scientific publication trends in Israel, 2005–2014**

Israeli publications have grown slowly since 2005

Countries of a similar economic size are given for comparison



1.15

Average citation rate for Israeli scientific publications 2008–2012; the OECD average is 1.08

11.9%

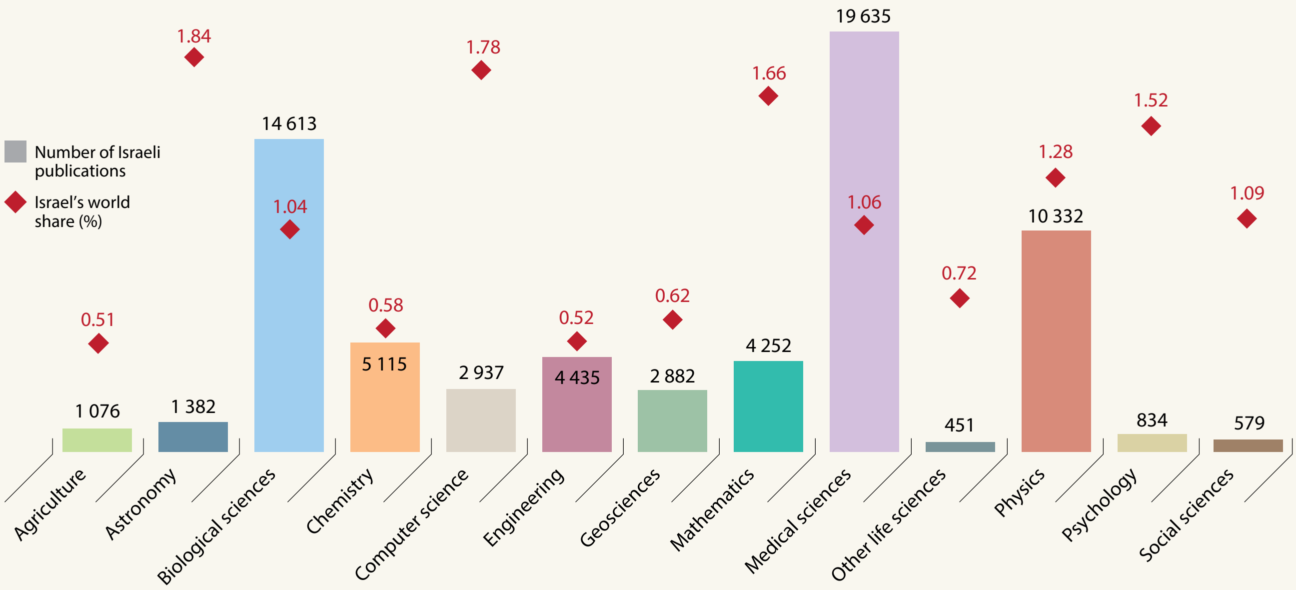
Share of Israeli papers among 10% most cited papers 2008–2012; OECD average is 11.1%

49.3%

Share of Israeli papers with foreign co-authors 2008–2014; the OECD average is 29.4%

Israel specializes in life sciences and physics

Cumulative totals by field, 2008–2014



Note: A further 6 745 papers are unclassified. Israel accounts for 0.1% of the global population.

Israeli scientists collaborate mostly with the USA and EU countries

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Israel	USA (19 506)	Germany (7 219)	UK (4 895)	France (4 422)	Italy (4 082)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

Four priority research areas which will impact daily life

The Israeli Science Foundation is the main source of research funding in Israel and receives administrative support from the Academy of Sciences and Humanities. The foundation provides competitive grants in three areas: exact sciences and technology; life sciences and medicine; and humanities and social sciences. Complementary funding is provided by binational foundations, such as the USA–Israel Binational Science Foundation (est. 1972) and the German–Israeli Foundation for Scientific Research and Development (est. 1986).

The Ministry of Science, Technology and Space funds thematic research centres and is responsible for international scientific co-operation. The Ministry's National Infrastructure Programme aims to create a critical mass of knowledge in national priority fields and to nurture the younger generation of scientists. Investment in the programme mainly takes the form of research grants, scholarships and knowledge centres. Over 80% of the ministry's budget is channelled towards research in academic institutions and research institutes, as well as towards revamping scientific infrastructure by upgrading existing research facilities and establishing new ones.

In 2012, the ministry resolved to invest NIS 120 million over three years in four designated priority areas for research: brain science; supercomputing and cybersecurity (Box 16.2); oceanography; and alternative transportation fuels. An expert panel headed by the Chief Scientist in the Ministry of Science, Technology and Space chose these four broad disciplines in the belief that they would would be likely to exert the greatest practical impact on Israeli life in the near future.

A rise in funding for space research

In 2012, the Ministry of Science, Technology and Space substantially increased its investment in the civil space programme administered by the Israel Space Agency (ISA). ISA's planned budget came to NIS 180 million for three years: NIS 65 million was allocated to fostering university–industry co-operation and NIS 90 million to joint international projects. In 2013, ISA signed contracts for a cumulative value

Box 16.2: **Israel launches cyber security initiative**

In 2013, hackers presumably used a cyber virus to shut down a major tunnel system in Israel for eight hours, causing massive traffic jams. Cyber attacks are a growing threat in Israel and worldwide.

In November 2010, the Israeli prime minister entrusted a task force with responsibility for formulating national plans to place Israel among the top five countries in the world for cyber security.

Less than a year later, on 7 August 2011, the government approved the establishment of the National Cyber Bureau to promote the Israeli cyber defence industry. The bureau is based in the Prime Minister's Office. The National Cyber Bureau allocated NIS 180 million (*circa* US$ 50 million) over 2012–2014 to encourage cyber research and dual military–civilian R&D; the funding is also being used to develop human capital, including through the creation of cyber security centres at Israeli universities that are funded jointly by the National Cyber Bureau and the universities themselves.

In January 2014, the prime minister launched CyberSpark, Israel's cyber innovation park, as part of plans to turn Israel into a global cyber hub. Located in the city of Beer-Sheva to foster economic development in southern Israel, CyberSpark is a geographical cluster of leading cyber companies, multinational corporations and universities, involving Ben Gurion University of the Negev, technology defence units, specialized educational platforms and the national Cyber Event Readiness Team.

About half of the firms in CyberSpark are Israeli, mostly small to medium-sized. Multinational companies operating in CyberSpark include EMC2, IBM, Lockheed Martin and Deutsche Telekom. PayPal recently acquired the Israeli start-up CyActive and has since announced plans to set up its second Israeli R&D centre in CyberSpark, with a focus on cyber security. This acquisition is just one of the many Israeli cybersecurity start-ups acquired by multinational companies in the past few years. Major acquisitions of Israeli start-ups in 2014 include Intellinx, purchased by Bottomline Technologies, and Cyvera, purchased by Palo Alto Networks.

The National Cyber Bureau recently estimated that the number of Israeli cyber defence companies had doubled in the past five years to about 300 by 2014. Israeli companies account for an estimated 10% of global sales, which currently total an estimated US$ 60 billion.

Total R&D spending on cyber defence in Israel quadrupled between 2010 and 2014 from US$ 50 million to US$ 200 million, bringing Israel's spending to about 15% of global R&D spending on cyber defence in 2014.

Cyber security technologies are exported by Israel in accordance with the Wassenaar Arrangement, a multilateral agreement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies.

Source: National Cyber Bureau; CyberSpark; Ministry of the Economy; Ziv (2015)
See: www.cyberspark.org.il

of NIS 88 million. The rest of the budget will be utilized in the coming years.

The aim of the national space programme is to enhance Israel's comparative advantage and place it among the world's top five countries in the field of space research and exploration. Israel plans to use its expertise in miniaturization and digitization to capture 3–5% of the US $ 250 billion global space market and generate US$ 5 billion in sales within ten years.

Over the next five years, ISA will be focusing on:

- joining the European Space Agency as a full or associate member;
- initiating and promoting two micro-research satellites;
- developing in-house knowledge, in order to increase the manufacturing capabilities of space systems and subsystems in Israel.

The ministry is also promoting collaboration with other leading countries in the field of space, including the USA, France, India, Italy, Japan and the Russian Federation, through co-operative ventures with the business sector.

Making science more approachable

Another objective of the ministry has been to bring the general public closer to science, particularly those living on Israel's periphery and the younger generation, by making science more approachable. This is done via science museums and annual events run by universities and science institutions, such as Researchers' Night.

Another tool used by the ministry has been the establishment of eight R&D centres since the 1980s on the country's geographical and social peripheries to spur local development and deepen community engagement in S&T. These centres have been established with the specific aim of drawing young, leading scientists to these parts of the country, along with raising the level of local education and fostering economic development. These R&D centres focus on finding solutions to local challenges.

A wealth of new funding programmes

The main ongoing programmes managed by the Office of the Chief Scientist within the Ministry of the Economy are: the Research and Development Fund; Magnet Tracks (est. 1994, Table 16.3); Tnufa (est. 2001) and the Incubator Programme (est.1991). Since 2010, the Office has initiated several new programmes (OCS, 2015):

- *Grand Challenges Israel (since 2014)*: an Israeli contribution to the Grand Challenges in Global Health programme, which is dedicated to tackling global health and food security challenges in developing countries; Grand Challenges Israel is offering grants of up to NIS 500 000 at the proof of concept/feasibility study stage.
- *R&D in the field of space technology (2012*)**:** encourages R&D to find technological solutions in various fields.
- *Technological Entrepreneurship Incubators (2014)*: encourages entrepreneurial technology and supports start-up technology companies.
- *Magnet – Kamin programme (2014)* provides direct support for applied research in academia that has potential for commercial application.
- *Cyber – Kidma programme* (2014): promotes Israel's cybersecurity industry.
- *Cleantech – Renewable Energy Technology Centre (2012)*: supports R&D through projects involving private–public partnerships in the field of renewable energy.
- *Life Sciences Fund (2010*)**:** finances the projects of Israeli companies, with emphasis on biopharmaceuticals; established together with the Ministry of Finance and the private sector.
- *Biotechnology – Tzatam programme* (2011): provides equipment to support R&D in life sciences. The Chief Scientist supports industrial organizations and the PBC provides research institutions with assistance.
- *Investment in high-tech industries (2011)*: encourages financial institutions to invest in knowledge-based industries, through a collaboration between the Office of the Chief Scientist and the Ministry of Finance.

Another source of public research funding is the Forum for National Research and Development Infrastructure (*Telem*). This voluntary partnership involves the Office of the Chief Scientist of the Ministry of the Economy and the Ministry of Science, Technology and Space, the Planning and Budgeting Committee and the Ministry of Finance. *Telem* projects focus on establishing infrastructure for R&D in areas that are of common interest to most Telem partners. These projects are financed by the *Telem* members' own resources.

Regular evaluations of policy instruments

The country's various policy instruments are evaluated by the Council for Higher Education, the National Council for Research and Development, the Office of the Chief Scientist, the Academy of Sciences and Humanities and the Ministry of Finance.

In recent years, the Magnet[7] administration in the Office of the Chief Scientist has initiated several evaluations of its own policy instruments, most of which have been carried out by independent research institutions. One such evaluation was carried out in 2010 by the Samuel Neaman Institute; it concerned the *Nofar* programme within the Magnet directorate.

7. Magnet is the acronym, in Hebrew, for Generic Pre-Competitive R&D.

Table 16.3: **Grants by the Israeli Office of the Chief Scientist, by R&D programme, 2008–2013, NIS**

Programme (year of creation)	2008	2009	2010	2011	2012	2013
Research and Development Fund (1984)	1 009.0	1 245.0	1 134.0	1 027.0	1 070.0	1 021.0
Magnet (1994)	159.0	199.0	159.0	187.0	134.0	138.0
Users Association (1995)	3.2	2.7	0.8	3.2	0.7	1.6
Magneton (2000)	31.1	30.8	32.9	26.8	28.0	23.8
R&D in Large Companies (2001)	71.0	82.0	75.0	63.0	55.0	59.0
Nofar (2002)	5.0	7.8	6.9	7.6	6.9	6.2
Traditional Industries Support (2005)	44.9	79.5	198.3	150.0	131.0	80.8
R&D Centres (2010)	4.6	14.8	10.9	7.6	8.6	8.2
Cleantech (2012)	65.4	95.4	100.7	81.9	84.4	105.6

Source: Office of the Chief Scientist, 2015

Nofar tries to bridge basic and applied research, before the commercial potential of a project has caught the eye of industry. The main recommendation was for *Nofar* to extend programme funding to emerging technological domains beyond biotechnology and nanotechnology (Getz *et al.*, 2010). The Office of the Chief Scientist accepted this recommendation and, consequently, decided to fund projects in the fields of medical devices, water and energy technology and multidisciplinary research.

An additional evaluation was carried out in 2008 by Applied Economics, an economic and management research-based consultancy, on the contribution of the high-tech sector to economic productivity in Israel. It found that the output per worker in companies that received support from the Office of the Chief Scientist was 19% higher than in 'twin' companies that had not received this support (Lach *et al.*, 2008). The same year, a committee headed by Israel Makov examined the Office of the Chief Scientist's support for R&D in large companies. The committee found economic justification for providing incentives for these companies (Makov, 2014).

Universities apply for 10% of Israeli patents

Since the 1990s, the traditional dual mission of universities of teaching and research has broadened to include a third mission: engagement with society and industry. This evolution has been a corollary of the rise of the electronics industry and information technology services, along with a surge in the number of R&D personnel following the wave of immigration from the former Soviet Union.

Israel has no specific legislation regulating the transfer of knowledge from the academic sector to the general public and industry. Nevertheless, the Israeli government influences policy formulation by universities and technology transfer by providing incentives and subsidies through programmes such as Magnet and Magneton (Table 16.3), as well as through regulation.

There were attempts in 2004 and 2005 to introduce bills encouraging the transfer of knowledge and technology for the public benefit but, as these attempts failed, each university has since defined its own policy (Elkin-Koren, 2007).

All Israeli research universities have technology transfer offices. Recent research conducted by the Samuel Neaman Institute has revealed that, in the past decade, the universities' share of patent applications constituted 10–12% of the total inventive activity of Israeli applicants (Getz *et al.*, 2013). This is one of the highest shares in the world and is largely due to the intensive activity of the universities' technology transfer offices.

The Weizmann Institute's technology transfer office, Yeda, has been ranked the third-most profitable[8] in the world (Weinreb, 2013). Through exemplary university–industry collaboration, the Weizmann Institute of Science and Teva Pharmaceutical Industries have discovered and developed the Copaxone drug for the treatment of multiple sclerosis. Copaxone is Teva's biggest-selling drug, with US$ 1.68 billion in sales in the first half of 2011 (Habib-Valdhorn, 2011). Since the drug's approval by the US Food and Drug Administration (FDA) in 1996, it is estimated that the Weizmann Institute of Science has earned nearly US$ 2 billion in royalties from the commercialization of its intellectual property. An additional revolutionary drug for the treatment of Parkinson's disease, Azilect, was developed by scientists from the Technion – Israel Institute of Technology. The drug was commercialized by the Technion Technology Transfer Office and the manufacturing license was given to Teva Pharmaceutical Industries. In 2014, the US Food and Drug Administration approved the Azilect label for treatment at all stages of

8. About 10–20% of the Weizmann Institute's annual budget of US$ 470 million comes from its commercialization company Yeda, which has a number of bestseller products. Yeda's annual income has been estimated at US$ 50–100 million (Weinreb, 2013).

Parkinson's disease. This means that the drug may be used alone, or in combination with other drugs, to treat Parkinson's disease.

Sustainability more visible in STI policy

In recent years, sustainability and environmental considerations have been increasingly taken into account in the formulation of general STI policies. Both internal and external forces are responsible for this trend. Among key internal drivers are the shortage of available land for development and the need for problem-solving to cope with population[9] growth. Among the external drivers are international and regional environmental agreements signed by Israel, such as the *Kyoto Protocol* to reign in climate change (1997) and the *Barcelona Convention for Protection against Pollution in the Mediterranean Sea* (1976), which set new environmental standards and benchmarks (Golovaty, 2006; UNESCO, forthcoming). It is the Ministry of Environmental Protection which is responsible for formulating an integrated nationwide policy to protect the environment.

Sustainability and environmental policies are being promoted through various legislative tools, including the Green Growth Act (2009) and Greenhouse Gas Emissions Reduction Act (2010), as well as through economic and R&D incentives. The government is targeting both the public and private sectors, with a focus on mitigating environmental hazards and maximizing efficiency by developing novel technologies in such fields as renewable energy or water treatment. A scheme has been initiated jointly by the Water Authority and the Ministry of Economics to match the investment cost of applying innovative water technologies; the government contributes 70%, the entrepreneur 15% and the local water utility a further 15%. Israel has one of the world's greatest capacities for desalination and the highest rate of water recycling. It has also developed a wide range of water-efficient technologies for agriculture. Some 85% of Israeli households use solar energy to heat water, equal to 4% of Israel's energy capacity. In 2014, Israel topped the rankings of the Global Cleantech Innovation Index, with 300 domestic companies active in this sector. In parallel, Israel is developing a non-renewable source of energy, natural gas, to ensure greater energy independence (Box 16.3).

9. Since peaking at 2.5% in 2007 after a wave of immigration, the annual population growth rate has dropped to a more sustainable rate of 1.1% (2014).

Targets for more sustainable development

Since 2008, the government has fixed a number of quantifiable targets for the country's sustainable development:

- a 20% reduction in electricity consumption by 2020 (government decision of September 2008);
- 10% of electricity to be generated from renewable sources by 2020, including a 5% milestone in 2014, which has not been met (government decision of January 2009);
- a 20% reduction in greenhouse gas emissions by 2020 over and above the target to 2020 for the 'business as usual' scenario (government decision of November 2010);
- A national plan for green growth is to be established covering the period 2012–2020 (government decision of October 2011).

Box 16.3: Natural gas: a chance to develop technologies and markets

Since 1999, large reserves of natural gas have been discovered off Israel's coast. This fossil fuel has become the primary fuel for electricity generation in Israel and is gradually replacing oil and coal. In 2010, 37% of electricity in Israel was generated from natural gas, leading to savings of US$ 1.4 billion for the economy. In 2015, this rate is expected to surpass 55%.

In addition, the usage of natural gas in industry – both as a source of energy and as a raw material – is rapidly expanding, alongside the requisite infrastructure. This is giving companies a competitive advantage by reducing their energy costs and lowering national emissions.

Since early 2013, almost the entire natural gas consumption of Israel has been supplied by the Tamar field, an Israeli–American private partnership. The estimated reserves amount to about 1 000 BCM, securing Israel's energy needs for many decades to come and making Israel a potentially major regional exporter of natural gas. In 2014, initial export agreements were signed with the Palestinian Authority, Jordan and Egypt; there are also plans to export natural gas to Turkey and the EU via Greece.

In 2011, the government asked the Academy of Sciences and Humanities to convene a panel of experts to consider the full range of implications of the most recent discoveries of natural gas. The panel recommended encouraging research into fossil fuels, training engineers and focusing research efforts on the impact of gas production on the Mediterranean Sea's ecosystem. The Mediterranean Sea Research Centre of Israel was established in 2012 with an initial budget of NIS 70 million; new study programmes have since been launched at the centre to train engineers and other professionals for the oil and gas industry.

Meanwhile, the Office of the Chief Scientist, among others, plans to use Israel's fledgling natural gas industry as a stepping stone to building capacity in advanced technology and opening up opportunities for Israeli innovation targeting the global oil and gas markets.

Source: IEC (2014); EIA (2013)

In order to reach these targets, the government has introduced a national programme to reduce greenhouse gas emissions. Its total budget for the period 2011–2020 amounts to NIS 2.2 billion (US$ 0.55 billion); in 2011–2012, NIS 539 million (US$ 135 million) was allocated to the following measures:

- Reduction of residential consumption of electricity;
- Support for emissions reduction projects in the industrial, commercial and public sectors;
- Support for innovative, environment-friendly Israeli technologies (NIS 40 million);
- Promotion of green construction, green building codes and related training;
- Introduction of educational programmes on energy efficiency and emissions reduction; and
- Promotion of energy efficiency regulation and energy surveys.

In May 2013, the programme became a casualty of national budget cuts and was suspended for three years. It is scheduled to resume in 2016 for a period of eight years. In its first three years of operation, the project generated NIS 830 million (US$ 207 million) in economic benefits:

- A reduction of 442 000 tons of greenhouse gases per year, with an annualized economic benefit of NIS 70 million;
- A reduction in electricity generation of 235 million kWh per year, with an annualized economic benefit of NIS 515 million; and
- A reduction in pollutant emissions and consequential health problems valued at NIS 244 million.

In 2010, the government launched a voluntary greenhouse gas emissions registry. As of 2014, the registry contained over 50 reporting organizations, which account for about 68% of Israel's greenhouse gas emissions. The registry respects international guidelines.

TRENDS IN PRIVATE SECTOR R&D

An attractive destination for multinational companies

Israel's high-tech industries are a spin-off of the explosive development of computer science and technology in the 1980s in such places as Silicon Valley and Massachusetts Route 128 in the USA, which ushered in the current high-tech era. Up until that point, Israel's economy had been essentially based on agriculture, mining and secondary sectors such as diamond polishing and manufacturing in textiles, fertilizers and plastics. The key factor which enabled ICT-based high-tech industries to take root and flourish in Israel was the massive investment by the defence and aerospace industries, which spawned new technologies and know-how. This formed the basis for Israel's unique high-tech industries in medical devices, electronics, telecommunications, computer software and hardware etc. (Trajtenberg, 2005). The massive Russian immigration of the 1990s reinforced this phenomenon, doubling the number of engineers and scientists in Israel overnight.

Today, Israel has the world's most R&D-intensive business sector; in 2013, it alone performed 3.49% of GDP. Competitive grants and tax incentives are the two main policy instruments supporting business R&D. Thanks to government incentives and the availability of highly trained human capital, Israel has become an attractive location for the R&D centres of leading multinationals. The country's STI ecosystem relies on both foreign multinationals and large corporate R&D investors, as well as on start-ups (OECD, 2014).

According to the Israel Venture Capital Database, 264 foreign R&D centres are currently active in Israel. Many of these centres are owned by large multinational firms that have acquired Israeli companies, technology and know-how and transformed them through mergers and acquisitions into their own local research facilities. The activity of some R&D centres even spans more than three decades, such as those of Intel, Applied Materials, Motorola and IBM.

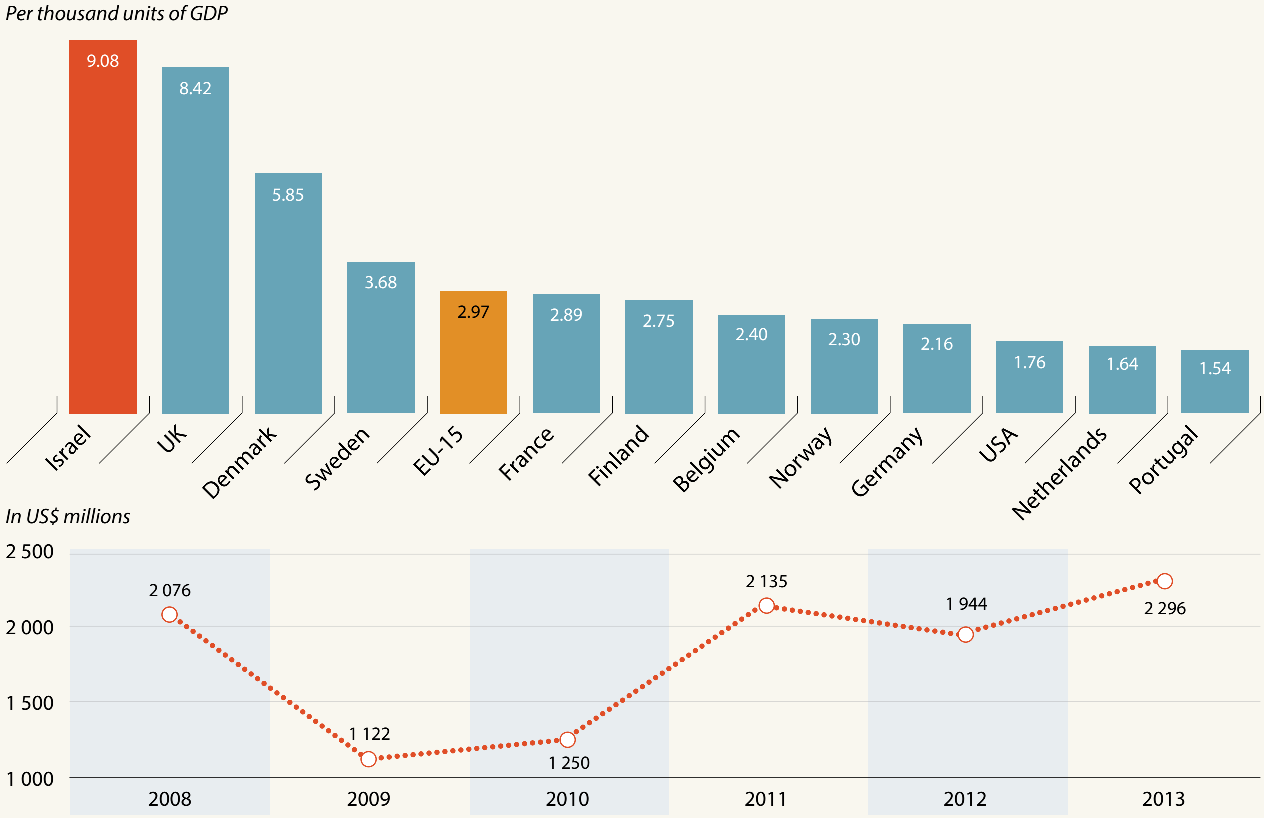
In 2011, foreign R&D centres employed 33 700 workers through local subsidiaries, two-thirds of whom (23 700) worked in R&D (CBS, 2014). The same year, these R&D centres spent a total of NIS 14.17 billion on R&D across the full spectrum of industry, up from 17% over the previous year.

A vibrant venture capital market

Israel's thriving start-up industry is complemented by a vibrant venture capital market, which attracted US$ 2 346 million in 2013 (IVC Research Centre, 2014). Over the past decade, the venture capital industry has played a fundamental role in the development of Israel's high-tech sector. By 2013, Israeli companies had raised more venture capital as a share of GDP than companies in any other country (Figure 16.12). Today, Israel is considered one of the biggest centres for venture capital in the world outside the USA.

Several factors have contributed to this growth. These include tax exemptions on Israeli venture capital, funds established in conjunction with large international banks and financial companies and the involvement of major organizations desirous to capitalize on the strengths of Israeli high-tech companies (BDO Israel, 2014). These organizations include some of the world's largest multinational companies, including Apple, Cisco, Google, IBM, Intel, Microsoft, Oracle Siemens and Samsung (Breznitz and Zehavi, 2007; IVC Research Centre, 2014). In recent years, the share of venture capital invested in the growth stages of enterprises has flourished at the expense of early stage investments.

Figure 16.12: **Venture capital raised by Israeli funds, 2013**



Source: Eurostat, OECD (2014); Israeli Venture Capital Research Centre

Foreigners: nearly 80% of applications to Israel Patent Office

Intellectual property rights in Israel protect copyright and performers' rights, trademarks, geographical indicators, patents, industrial designs, topographies of integrated circuits, plant breeds and undisclosed business secrets. Both contemporary Israeli legislation and case law are influenced by laws and practices in modern countries, particularly Anglo-American law, the emerging body of EU law and proposals by international organizations (OECD, 2011).

Israel has made a concerted effort to improve the economy's ability to benefit from an enhanced system of intellectual property rights. This includes increasing the resources of the Israel Patent Office, upgrading enforcement activities and implementing programmes to bring ideas funded by government research to the market (OECD, 2011).

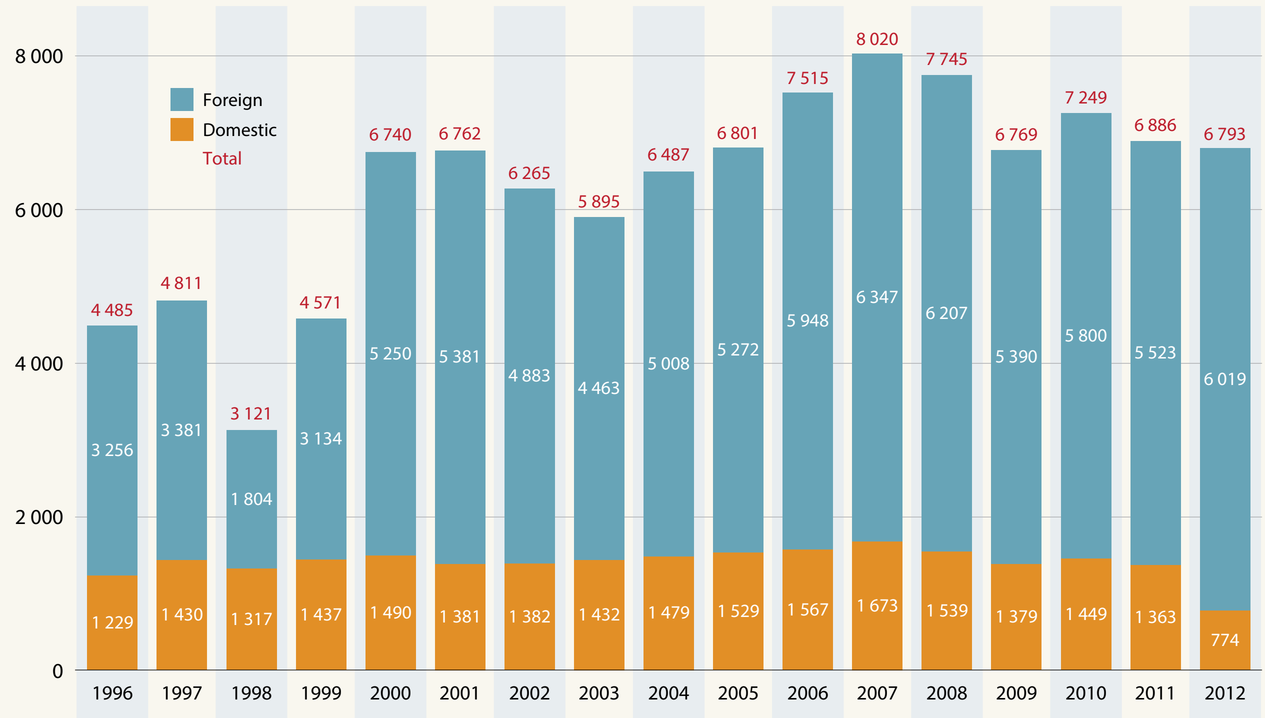
Foreigners account for nearly 80% of the patent applications filed with the Israel Patent Office since 2002 (Figure 16.13). A sizeable share of foreign applicants seeking protection from the Israel Patent Office are pharmaceutical companies such as F. Hoffmann-La Roche, Janssen, Novartis, Merck, Bayer-Schering, Sanofi-Aventis and Pfizer, which happen to be the main business competitors of Israel's own Teva Pharmaceutical Industries.

Israel ranks tenth for the number of patent applications filed with the United States Patent and Trademark Office (USPTO) by country of residence of the first-named inventor (Figure 16.14). Israeli inventors file far more applications with USPTO (5 436 in 2011) than with the European Patent Office (EPO). Moreover, the number of Israeli filings with EPO dropped from 1 400 to 1 063 between 2006 and 2011.

This preference for USPTO is largely due to the fact that foreign R&D centres implanted in Israel are primarily owned by US firms such as IBM, Intel, Sandisk, Microsoft, Applied Materials, Qualcomm, Motorola, Google or Hewlett–Packard. The inventions of these companies are attributed to Israel as the inventor of the patent but not as the owner (applicant or assignee).

The loss of intellectual property into the hands of multinationals occurs mainly through the recruitment of the best Israeli talent by the local R&D centres of multinational firms. Although the Israeli economy benefits from the activity of the multinationals' subsidiaries through job creation and other means, the advantages are relatively small compared to the potential economic gains that might have been achieved, had this intellectual property been utilized to support and foster the expansion of mature Israeli companies of a considerable size (Getz *et al.*, 2014; UNESCO, 2012).

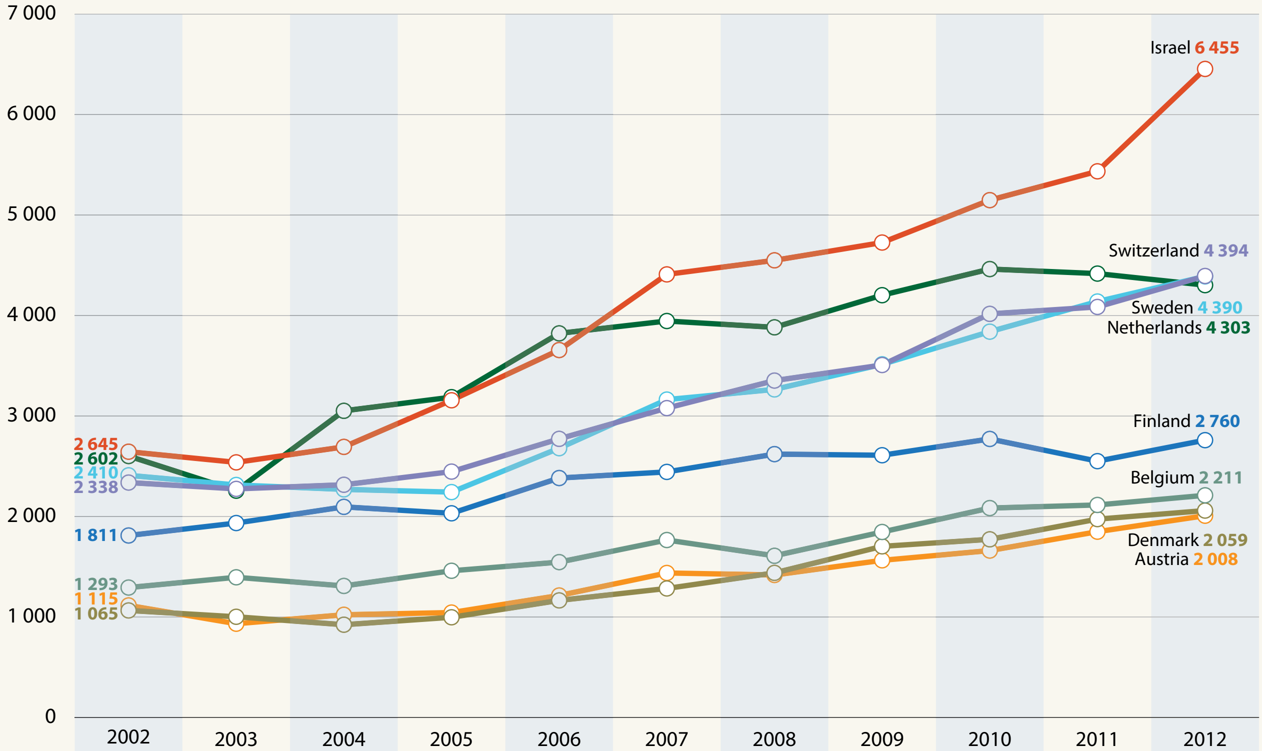
Figure 16.13: **Domestic and foreign patent applications to the Israeli Patent Office, 1996–2012**



Source: Israel Patent Office

Figure 16.14: **Israeli patent applications filed with USPTO, 2002–2012**

By inventor's country of residence, other countries with a similar population size are given for comparison



Note: The top two countries registered 268 782 (USA) and 88 686 (Japan) patents respectively in 2012. Israel ranked tenth worldwide.
Source: USPTO

TRENDS IN SCIENTIFIC CO-OPERATION

Broad collaboration around the world

Israel collaborates in STI with a wide range of countries, regions and international organizations. The Israel Academy of Sciences and Humanities has official agreements with 38 institutions (mostly national academies) in 35 European countries, as well as with countries in North and South America, the Indian subcontinent and Southeast Asia.

Israel has been associated with the EU's framework programmes on research and innovation since 1996. Between 2007 and 2013, Israeli public and private institutions contributed their scientific expertise to over 1 500 projects.

Israel also participates in other EU programmes, such as those of the European Research Council or European Biology Laboratory. Israel joined the European Organization for Nuclear Research (CERN) in 2014, after having participated in its activities since 1991 and becoming an associated member in 2011. Israel has been a Scientific Associate of the European Synchrotron Radiation Facility since 1999; the agreement was renewed in 2013 for a fourth term of five years and notably raised Israel's contribution from 0.5% to 1.5% of ESRF's budget. Israel is also one of the ten founding members of the European Molecular Biology Laboratory, which dates from 1974.

In 2012, the Weizmann Institute of Science, together with Tel Aviv University, was chosen as one of the seven core centres of the new Integrated Structural Biology Infrastructure (Instruct), joining prestigious institutions in France and Germany, Italy and the UK. Israel has been selected as one of the seven nodes of the European Strategy Forum of Research Infrastructure, which is establishing about 40 such nodes in total, seven of them in biomedical sciences. The aim of the biomedical Instruct is to provide pan-European users with access to state-of-the-art equipment, technologies and personnel in cellular structural biology, to enable Europe to maintain a competitive edge in this vital research area.

Israel is also one of the nodes of Elixir, which orchestrates the collection, quality control and archiving of large amounts of biological data produced by life science experiments in Europe. Some of these datasets are highly specialized and were previously only available to researchers within the country in which they were generated.

The USA is one of Israel's closest partners in STI. Some collaborative projects are funded through binational funds such as the Binational Industrial Research and Development (BIRD) foundation, which awarded US$ 37 million in grant payments for binational R&D projects from 2010 to 2014, according to its 2014 annual report. Other examples are the Binational Agricultural Research and Development fund, the US–Israel Science and Technology Foundation and the US–Israel Binational Science foundation. The Israeli Industry Centre for R&D, which falls under the Ministry of the Economy, implements bilateral co-operation agreements with various US federated states. The most recent agreements were concluded in 2011 with the State of Massachusetts in life sciences and clean technology and with the State of New York in energy, ICTs and nanotechnology.

Israel's long-lasting collaboration with Germany continues to grow. For example, the annual budget of the German–Israel Foundation for R&D (GIF) increased by € 4.8 million per year between 2010 and 2012 and by € 5 million per year from 2014 to 2016. In the past two years, GIF has distributed about € 12 million per year through the grants it provides to the regular programme and the young scientists programme.

The Israeli Industry Centre for R&D supports co-operative projects through other binational funds, such as the Canada–Israel Industrial Research and Development Foundation, the Korean–Israel Industrial Research and Development Foundation and the Singapore–Israel Industrial Research and Development Foundation.

In 2006, the Israeli and Indian ministers of agriculture signed a long-term agreement for co-operation and training. This was followed two years later by a US$ 50 million shared agricultural fund, focusing on dairy, farming technology and micro-irrigation. In 2011, Israel and India signed a co-operation agreement on urban water systems. In May 2013, the two countries signed an agreement for the establishment of 28 centres of excellence in agriculture. The first 10 centres of excellence specialize in mangoes, pomegranates and citrus fruits. They have been operational since March 2014 and are already offering farmers free training sessions in efficient agricultural techniques such as vertical farming, drip irrigation and soil solarization.

In 2010, the Israeli Industry Centre for R&D established the China–Israel Industrial Research and Development Cooperation Programme. Industrial co-operation agreements have also been signed with the provinces or municipalities of Jiangsu (2008), Shanghai (2011) and Shenzhen (2011). The India–Israel Industrial Research and Development co-operation framework (i4RD) was signed in 2005.

In 2012, the Israel Science foundation and the Natural Science Foundation of China signed an agreement establishing a fund for joint research co-operation. Current schemes involving Israeli academic institutions include the Tel Aviv University–Tsinghua University initiative for the establishment of a joint technological research centre in Beijing and the Technion's planned branch in Guangdong Province for studies in the field of science and engineering. Within trilateral co-operation, Israel, Canada and China established a joint hub in agricultural technologies in China in 2013 (see Box 4.1).

Another example of trilateral co-operation is the Africa Initiative signed by Israel, Germany and Ghana in 2012. The three implementing partners are the Israeli and German agencies for international development co-operation, Mashav and GIZ, and Ghana's Ministry of Food and Agriculture. The aim is to develop a thriving citrus value chain in Ghana, in line with the ministry's policy of enhancing productivity to improve the livelihoods of farmers.

In October 2013, the Israeli Minister of Agriculture signed an agreement establishing a joint Israeli–Vietnamese fund for agricultural R&D, together with a free-trade agreement between the two countries.

Projects in the Middle East

Israel participates in the intergovernmental project for a Synchrotron Light Source for Experimental Science and Applications in the Middle East (SESAME), a 'third-generation' synchrotron light source in Allan (Jordan) which functions under the auspices of UNESCO. The current members of SESAME are Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey. The SESAME facility is expected to be fully operational by 2017 (see Box 17.3).

The Israeli Academic Centre in Cairo was initiated in 1982 by the Israel Academy of Sciences and Humanities. Funded by the Council for higher Education, it is entrusted with the task of strengthening research ties between universities and researchers in Israel and Egypt. The centre operated successfully until 2011 when the political climate in Egypt cooled towards Israel. Since that time, the centre has operated on a smaller scale.

The Israel Academy of Sciences and Humanities and the International Continental Drilling Programme initiated a deep-drilling expedition to the Dead Sea in 2010. Researchers from six countries participated in this scientific project, which was implemented jointly by Israel, Jordan and the Palestinian Authority.

The Israeli–Palestinian Medical and Veterinary Research Collaboration is one recent example of inter-university collaboration between Israel and the Palestinian Authority. This collaborative public health project between the Hebrew University of Jerusalem's School of Veterinary Medicine and the Al Quds Public Health Society was launched in 2014 with funding from the Dutch Ministry of Foreign Affairs.

Also of note is the Israeli–Palestinian Scientific Organization (IPSO), a non-political, non-profit organization founded over a decade ago and based in Jerusalem. Among joint research projects, one in nanotechnology stands out. It involved Israeli chemist Danny Porath at the Hebrew University of Jerusalem and one of his doctoral students, Palestinian chemist Mukhles Sowwan from Al-Quds University. Their joint research project enabled Prof. Sowwan to establish the first nanotechnology laboratory at Al-Quds University. IPSO had planned to issue a call for research proposals in late 2014, having raised about half of the requisite funding, but this call appears to have been delayed.

CONCLUSION

A need to prepare for tomorrow's science-based industries

The Israeli economy is driven by industries based on electronics, computers and communication technologies, the result of over 50 years of investment in the country's defence infrastructure. Israeli defence industries have traditionally focused on electronics, avionics and related systems. The development of these systems has given Israeli high-tech industries a qualitative edge in civilian spin-offs in the software, communications and Internet sectors.

However, the next waves of high technologies are expected to emanate from other disciplines, including molecular biology, biotechnology and pharmaceuticals, nanotechnology, material sciences and chemistry, in intimate synergy with ICTs. These disciplines are rooted in the basic research laboratories of universities rather than the defence industries. This poses a dilemma. In the absence of a national policy for universities, let alone for the higher education system as a whole, it is not clear how these institutions will manage to supply the knowledge, skills and human resources needed for these new science-based industries.

There is no single 'umbrella-type' organization that co-ordinates all of STI and formulates STI policy in Israel. In order to safeguard the long-term relevance of Israeli R&D and the country's innovation capabilities, a holistic R&D framework and strategy should be implemented. This framework should involve the various actors of the STI system: the Office of the Chief Scientist in the Ministry of the Economy and other government ministries, Israel's research universities and research centres of excellence, its hospitals and academic medical centres and its corporate R&D laboratories.

The *Sixth Higher Education Plan* (2011–2015) sets out to improve the quality and competitiveness of the higher education system. It contains important recommendations, such as that of raising the number of academic staff by about 850 over the next six years and encouraging minorities to study at university in anticipation of the looming shortage of professionals in Israel. Enhancing the integration of ultra-orthodox men and Arab women in the labour force and their educational level will be vital to safeguard Israel's growth potential in the years to come.

The *Sixth Higher Education Plan* sidesteps one key issue, however. Israel's universities are neither equipped, nor sufficiently funded to be at the forefront of science and technology in the 21st century. Funding of research infrastructure is particularly worrying because, in decades past, insufficient government funding has been greatly compensated by philanthropic contributions from the American Jewish community. This contribution is expected to diminish significantly.

Long-term economic growth cannot be attained without improving the productivity of the traditional industrial and services sector. The remedy could lie in giving employers incentives to implement innovation, by encouraging them to assimilate advanced technologies, adopt organizational changes and new business models and augment the share of exports in their output.

Globalization presents both tremendous challenges and opportunities for Israel's high-tech industry. An economy centred on delivering innovation and added value could give companies a huge competitive advantage in the global market in the years to come, as multinational companies are continually seeking new ideas and unique products to serve unmet needs.

In recent years, scientific research in interdisciplinary frontier fields such as bioinformatics, synthetic biology, nanobiology, computational biology, tissue biology, biomaterials, system biology and neuroscience, has evolved rapidly in Israeli academia but not shown the same intensity in Israeli industry. These new interdisciplinary and converging fields are likely to constitute the next growth engines for the global economy. Regulatory and targeted policy measures should be formulated by the Israeli authorities to create the necessary infrastructure to absorb the fruits of academic research in these fields and integrate, convert and adapt the fruits of this research to wider economic and practical use.

KEY TARGETS FOR ISRAEL

- Raise industrial-level productivity – the value added by each employee – from PPP$ 63 996 in 2014 to PPP$ 82 247 by 2020;
- Increase the number of university faculty by 15% and the teaching staff of colleges by 25% by 2018;
- Capture a 3–5% share of the US $ 250 billion global space market with a sales volume of US$ 5 billion by 2022;
- Reduce electricity consumption by 20% between 2008 and 2020;
- Generate 10% of electricity from renewable sources by 2020.

REFERENCES

BDO Israel (2014) *Doing business in Israel. See: www.bdo.co.il*

Ben David, D. (2014) *State of the Nation Report: Society, Economy and Policy in Israel*. Taub Centre for Social Policy Studies in Israel: Jerusalem.

Breznitz, D. and A. Zehavi (2007) *The Limits of Capital: Transcending the Public Financer – Private Producer Split in R&D.* Technology and the Economy Programme STE-WP-40. Samuel Neaman Institute: Haifa.

Brodet, D. (2008) *Israel 2028: Vision and Strategy for the Economy and Society in a Global World.* Presented by a public committee chaired by Eli Hurvitz. US–Israel Science and Technology Foundation.

CBS (2014) Business Research and Development 2011, Publication No. 1564. Israeli Central Bureau of Statistics.

CHE (2014) *The Higher Education System in Israel: 2014* (in Hebrew). Council for Higher Education's Planning and Budgeting Committee.

EIA (2013) *Overview of Oil and Natural Gas in the Eastern Mediterranean Region.* US Energy Information Administration, Department of Energy: Washington, DC.

Elkin-Koren, N. (2007) *The Ramifications of Technology Transfer Based on Intellectual Property Licensing* (in Hebrew). Samuel Neaman Institute: Haifa.

Fatal, V. (2013) *Description and analysis of wage differentials in Israel in recent years* (in Hebrew). The Knesset's Research and Information Centre: Jerusalem.

Flug, K. (2015) Productivity in Israel - the Key to Increasing the Standard of Living: Overview and a Look Ahead. Speech by the Governor of the Bank of Israel , Israel Economic Association Conference. Bank of Israel.

Frenkel, A. and E. Leck (2006) *Investments in Higher Education and the Economic Performance of OECD Countries: Israel in a Comparative Perspective* (in Hebrew, English abstract). Samuel Neaman Institute, Technion – Israel Institute of Technology: Haifa.

Getz, D.; Leck, E. and A. Hefetz (2013a). *R&D Output in Israel: a Comparative Analysis of PCT Applications and Distinct Israeli Inventions* (in Hebrew). Samuel Neaman Institute: Haifa.

Getz, D.; Leck, E. and V. Segal (2014). *Innovation of Foreign R&D Centres in Israel: Evidence from Patent and Firm-level data*. Samuel Neaman Institute: Haifa.

Getz, D.; Segal, V.; Leck, E. and I. Eyal (2010) *Evaluation of the Nofar Programme* (in Hebrew). Samuel Neaman Institute: Haifa.

Golovaty, J. (2006) *Identifying Complementary Measures to Ensure the Maximum Realisation of benefits from the Liberalisation of Environmental Goods and Services. Case study: Israel*. Organisation for Economic Co-operation and Development. Trade and Environment Working Paper No. 2004–06.

Habib-Valdhorn, S. (2011) *Copaxone Patent Court Hearing opens Wednesday*. See: www.globes.co.il.

IEC (2014) *2013 Annual Report*. Tel-Aviv Stock Exchange. Israel Electric Corporation.

IVC Research Centre (2014) *Summary of Israeli High-Tech Capital Raising*. Israeli Venture Capital Research Centre. See: www.ivc-online.com

Lach, S.; Parizat, S. and D. Wasserteil (2008). *The impact of government support to industrial R&D on the Israeli economy*. Final report by Applied Economics. The English translation from Hebrew was published in 2014.

Makov, I. (2014) *Report of the Committee Examining Government Support for Research and Development in Large Companies* (in Hebrew). See: www.moital.gov.il

Ministry of the Economy (2015) R&D Incentive Programmes. Office of the Chief Scientist.

Ministry of Finance (2014) *Managing the Fiscal Policy Goals*. General Accountant. See: www.ag.mof.gov.ill

MIT (2011) *The Third Revolution: the Convergence of the Life Sciences, Physical Sciences and Engineering*. Massachusetts Institute of Technology: Washington DC.

OECD (2014) Israel. In: OECD Science, Technology and Industry Outlook 2014. Organisation for Economic Co-operation and Development: Paris.

OECD (2011) *Enhancing Market Openness, Intellectual Property Rights and Compliance through Regulatory Reform in Israel*. Organisation for Economic Co-operation and Development. See: www.oecd.org/israel/48262991.pdf

Trajtenberg, M. (2005) *Innovation Policy for Development: an Overview STE-WP-34*. Samuel Neaman Institute: Haifa.

UNESCO (forthcoming) *Mapping Research and Innovation in Israel*. UNESCO's Global Observatory of STI Policy Instruments: Country Profiles in Science, Technology and Innovation Policy, volume 5.

UNESCO (2012) The high level of basic research and innovation promotes Israeli science-based industries. Interview of Professor Ruth Arnon. *A World of Science*, 10 (3) March.

Weinreb, G. (2013) *Yeda earns $50–100m annually*. Retrieved from www.globes.co.il.

Ziv, A. (2015). Israel emerges as global cyber superpower. *Haaretz*, 26 May.

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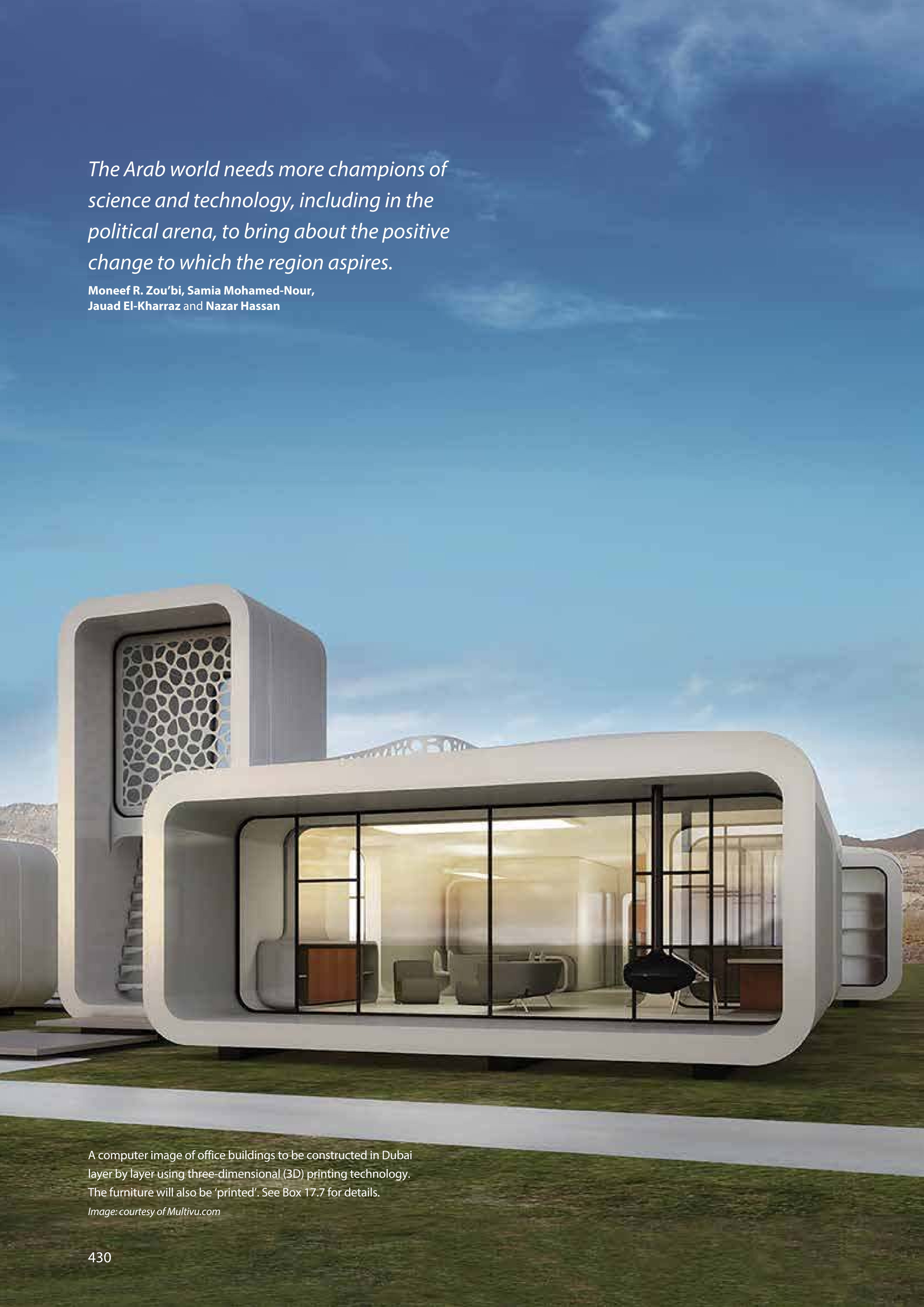


The Arab world needs more champions of science and technology, including in the political arena, to bring about the positive change to which the region aspires.

Moneef R. Zou'bi, Samia Mohamed-Nour, Jauad El-Kharraz and **Nazar Hassan**

A computer image of office buildings to be constructed in Dubai layer by layer using three-dimensional (3D) printing technology. The furniture will also be 'printed'. See Box 17.7 for details.

Image: courtesy of Multivu.com

17 · The Arab States

Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Sudan, Tunisia, United Arab Emirates, Yemen

Moneef R. Zou'bi, Samia Mohamed-Nour, Jauad El-Kharraz and Nazar Hassan

INTRODUCTION

The global financial crisis has ricocheted on the region

The Arab world[1] is of strategic importance, owing to its location and wealth of oil and natural gas: 57% of the world's proven oil reserves and 28% of those for gas (AFESD *et al*, 2013).

The tremors of the global financial crises of 2008 and 2009 and the subsequent recession in most developed countries affected Arab states in a variety of ways. The oil-exporting countries of the Gulf Cooperation Council felt such tremors, most being characterized by open financial and commercial systems with high exposure to global financial markets and close association with the global commodity markets (AFESD *et al*, 2010). Not so countries such as Algeria, Libya, Sudan and Yemen, where local capital markets are not directly linked to global markets. However, as their economies also rely on oil revenue, the Brent crude price significantly affects their fiscal policy.

In, Egypt, Jordan, Lebanon, Mauritania, Morocco, Syria and Tunisia, where the banking sector is dependent on national borrowing sources, the economy was not directly affected by fluctuations in global capital markets. Such countries nevertheless felt these external economic shocks through their close association with the markets of developed countries and other major trading partners in the European Union (EU) and USA. Needless to say, their exports depend primarily on demand from the developed countries, in addition to income from tourism, remittances from expatriate workers and foreign direct investment (FDI) flows (AFESD *et al*, 2010).

The inability of most Arab countries since 2008 to address socio-economic needs effectively and ensure that their economies have kept pace with population growth has created widespread frustration. Even before the economic crisis of 2008, unemployment in the Arab world was high,[2] at around 12%. Young job seekers constitute over 40% of the region's unemployed. Today, over 30% of the population of Arab states is aged less than 15 years. As of 2013, most Arab states had achieved a gross tertiary enrolment rate of more than 30% and even above 40% for Jordan, Lebanon, Palestine and Saudi Arabia but they have failed to create the appropriate value chain of job openings required to absorb the spreading pool of graduates.

1. Although members of the League of Arab States, Djibouti and Somalia are profiled in Chapter 19 on East and Central Africa.

2. with a few exceptions, such as Kuwait, Qatar and the United Arab Emirates

The Arab region: from hope to turmoil

The so-called Arab Spring was triggered by demonstrations in Tunisia in December 2010. Popular unrest quickly spread across the region, revealing a common aspiration towards freedom, dignity and justice (ESCWA, 2014a).

Since December 2010, Arab countries have undergone extraordinary transformations, including regime change in Egypt, Libya, Tunisia and Yemen and the descent of Syria into civil war after what began as peaceful protests in the spring of 2011. Despite having elected parliaments, Jordan and Bahrain also witnessed a series of demonstrations in favour of reform in 2011. In Jordan, the protests were essentially directed against the failure of successive governments to address serious economic issues and combat unemployment. In Bahrain, demonstrations were more political in nature and, to some extent, sectarian.

In part, the upheaval in the Arab world was a reaction by technology-savvy young Arabs to decades of political stagnation and the failure of some Arab governments to afford people adequate levels of socio-economic development. Within a couple of years, however, the failure of the Arab Spring to deliver on its promises had left many disillusioned. One of the great beneficiaries of the Arab Spring was the Muslim Brotherhood movement, which won the election in Egypt in mid-2012; barely a year later, President Mohamed Morsi was deposed, following mass popular protests at the Muslim Brotherhood's failure to build a national consensus to address the country's problems. Since 2015, there have been repeated clashes between the government of President Abdel Fattah al-Sissi and the Muslim Brotherhood, which is now considered a terrorist organization by the governments of several Arab and non-Arab countries, including Bahrain, Egypt, the Russian Federation, Saudi Arabia, Syria and the United Arab Emirates. The Egyptian government has, meanwhile, forged ahead with its ambitious expansion of the Suez Canal (Box 17.1) and, in March 2015, organized a major conference in Sharm El-Sheikh on the theme of economic development (see p. 435).

Military spending is eating up resources for development

Military spending in the Middle East increased by 4% in 2013 to an estimated US$ 150 billion. Saudi Arabia's own budget shot up by 14% to US$ 67 billion, allowing it to leapfrog over the UK, Japan and France to become the world's fourth-largest military spender behind the USA, China and the Russian Federation, according to the Stockholm International

Box 17.1: **Upgrading the Suez Canal**

The Suez Canal provides a vital shipping link between Europe and Asia. On 5 August 2014, Egyptian President Abdel Fattah Al-Sissi announced plans for a 'new' Suez Canal that would run in parallel to the current waterway. This was to be the first major expansion of this vital trading route in its 145-year history.

The Egyptian plan to upgrade the Suez Canal could raise its capacity from 49 to 97 passing ships a day by 2023. The current Suez Canal, which connects the Mediterranean with the Red Sea, can mostly only facilitate one-way traffic and is too narrow at some points for vessels to pass one another. The new canal is expected to solve this problem and thereby cut the waiting time for ships from 11 to 3 hours. The area around the canal (76 000 km^2) is being turned into an international industrial and logistics hub. Officials expect the new development to boost annual revenue from the canal, which is operated by the state-owned Suez Canal Authority, from US$ 5 billion at present to US$ 13.5 billion. In October 2014, work began on deepening the Suez Canal.

Some shipping industry executives had expressed doubts as to whether Egypt could obtain sufficient funding to finish the project on schedule. The Egyptian government was adamant that the project would not be dependent on foreign funding. By September 2014, the total amount needed (US$ 8.4 billion) had been raised, according to the Egyptian central bank, through the issuance of 500 million shares reserved for Egyptians. The government inaugurated the new canal on 6 August 2015.

Despite widespread acknowledgment that the project is an economic necessity, some scientists fear that that it could damage the marine ecosystem. A group of 18 scientists from 12 countries published a letter in 2014 in the journal of *Biological Invasions* calling on the Egyptian government to take steps to minimize any ecological damage.

Source: compiled by authors

Peace Research Institute[3] (see also Figure 17.1) However, the largest increase in the region (27%) came from Iraq, which is reconstituting its armed forces.

The escalating pressures on Arab states, particularly those related to security and counterterrorism – including military confrontations with radical groups such as Al Qaida and Da'esh –, have spurred the governments of these countries to increase their own military spending.

Still a long way to go to improve governance

There is little doubt that corruption has played a pivotal role in the outbreak of turmoil since 2010. Available estimates suggest that the smuggling of funds amounted annually to US$ 2 billion in Egypt and US$ 1 billion in Tunisia, according to the institution charged with monitoring the soundness of the global financial sector (Global Financial Integrity, 2013). This amount represented 3.5% of Tunisia's GDP and 2% of Egypt's in 2005.

Government effectiveness has deteriorated in several Arab countries. Kaufmann *et al*. (2013) found that, in the Arab world, only the United Arab Emirates (UAE) and Qatar ranked above the 80th percentile in 2013. Bahrain and Oman ranked between the 60th and 70th percentiles and five countries between the 50th and 60th percentiles, namely, Jordan, Kuwait, Morocco, Saudi Arabia and Tunisia.

The voice and accountability indicator over the past ten years has been disappointing, according to Kaufmann *et al.* (2011; 2013). In 2013, the scores for the top five Arab states (Tunisia, Lebanon, Morocco, Kuwait and Jordan) were low by international standards (between the 45th and 25th percentiles). Algeria, Iraq, Libya and Palestine show some improvement but, overall, 12 Arab states registered a decline in voice and accountability between 2003 and 2013, namely: Algeria, Bahrain, Djibouti, Egypt, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Sudan, Syria and the United Arab Emirates.

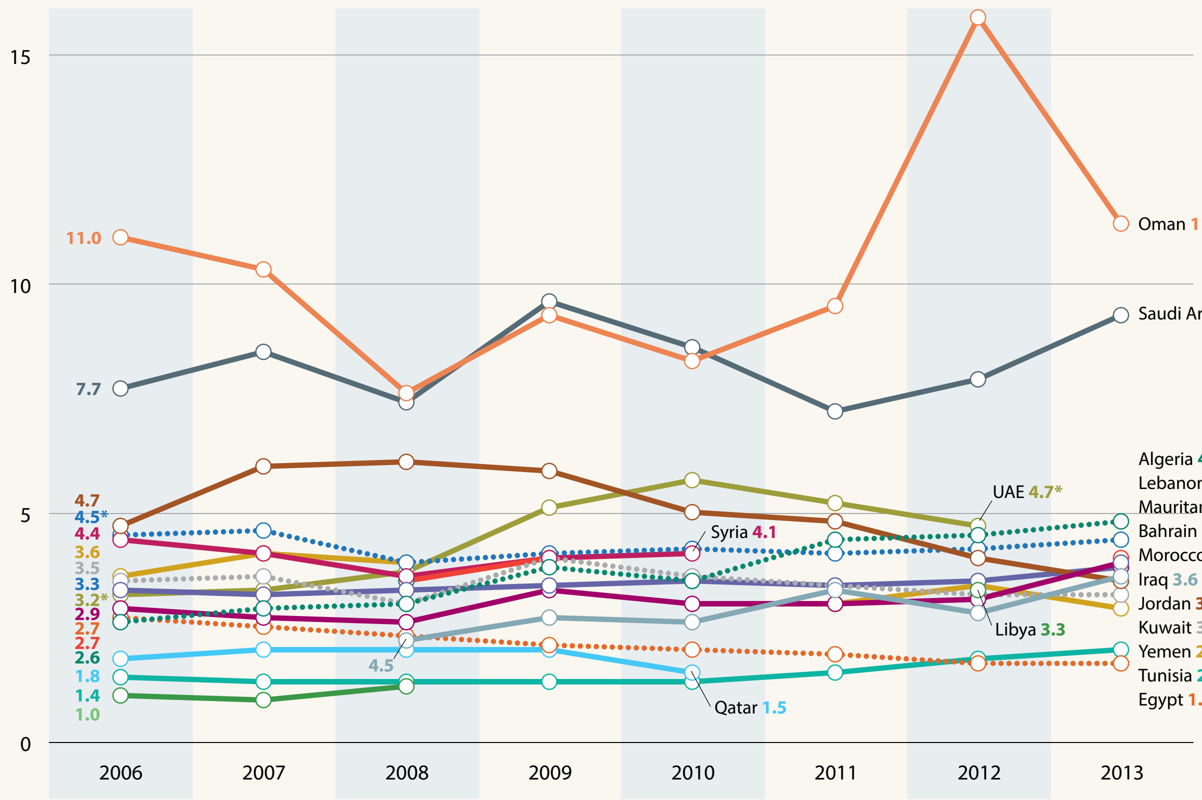
An economic downturn in most Mashreq countries

The countries of the Mashreq have a population of about 196 million, or 53.4% of the Arab population. With the exception of Iraq, they have few oil reserves. Thanks to high commodity prices for oil, Iraq was able to weather the global financial crisis better than its neighbours. The slump in Sudan's economy in 2012, however, was more a consequence of the birth of South Sudan in 2011 and subsequent skirmishes between the two Sudans than the impact of global shocks.

In 2013, GDP per capita in the Mashreq countries, Egypt and Sudan was highest in Lebanon and lowest in Sudan. From 2008 to 2013, annual growth slowed in all the countries of this group, even though it was less noticeable in Palestine in 2013. Over the same period, unemployment rates changed little in all but Egypt, where the slump in tourism and FDI following the revolution in 2011 pushed up unemployment (Table 17.1). With the return to stability, GDP growth recovered to 2.9% in 2014 and is expected to hit 3.6% in 2015. Economic growth

3. See: www.sipri.org/media/pressreleases/2014/Milex_April_2014 (accessed 16 January 2015)

Figure 17.1: **Military expenditure in selected Arab states as a % of GDP, 2006–2013**



*SIPRI estimate

Note: The low figure for Egypt (1.7%) in 2013 only tells half the story, as it excludes the economic activities of the Egyptian armed forces and American aid, which cover 80% of military procurement (Gaub, 2014).

Source: Stockholm International Peace Research Institute database, accessed January 2015

in Jordan and Lebanon, in particular, has been affected by the massive influx of Syrian refugees since 2011.

Together with Egypt and Sudan, the Mashreq countries are considered reservoirs of human talent which supply neighbouring states with teaching faculty, researchers and both skilled and unskilled workers. Egypt, Iraq Jordan, Lebanon, Palestine,[4] Sudan and Syria all boast relatively mature higher education infrastructure that includes some of the oldest universities in the Arab world, including the American University of Beirut (1866) and Cairo University (1908).

The Arab Spring has left a big imprint on the Libyan economy

Since 2008, the Maghreb countries have experienced mixed fortunes. Whereas the economies of Algeria and Mauritania have maintained healthy growth rates, countries directly affected by the Arab Spring have witnessed a more negative trend. Growth slowed to 2.2% in Tunisia and even contracted by 11.6% in Libya (Table 17.1). However, unemployment rates have remained unchanged, with variations from one country to another. Despite average growth of 5.9% between 2011 and 2013, Mauritania's unemployment rate was as high as 31% in 2013, indicating that growth had not been sufficient to provide much-needed jobs.

The Gulf States contribute nearly half of the Arab world's GDP

The six Gulf States, which contribute about 47% of total Arab GDP, are all economically dependent on oil. Some 75 million people (including a sizeable foreign labour force) belong to this group, representing around 20.4% of the Arab world population in 2014 (Table 17.1).

In 2014, the economy slowed in Oman and Qatar, primarily as a consequence of weaker exports and the drop in both private consumption and investment. At the same time, Kuwait and Saudi Arabia emerged from a period of economic contraction, with several sectors showing signs of recovery, including housing in Kuwait and banking in Saudi Arabia.

4. On 29 November 2012, the United Nations General Assembly voted to grant Palestine non-member observer status at the United Nations. Palestine has been a member of UNESCO since 31 October 2011.

Table 17.1: **Socio-economic indicators for the Arab States, 2008 and 2013**

	Population ('000s)		GDP per capita (current PPP$)		GDP average annual growth (%)		Employment rate (% of adult population)		Unemployment rate (% of labour force)	
	2008	2013	2008	2013	2008 – 2010	2011 – 2013*	2008	2013	2008	2013
Gulf States plus Yemen										
Bahrain	1 116	1 332	40 872	43 824	4.4	3.7	63.9	65.0	7.8	7.4
Kuwait	2 702	3 369	95 094	85 660^{-1}	-2.4	6.1	66.0	66.3	1.8	3.1
Oman	2 594	3 632	46 677	44 052	6.4	2.2	52.1	59.9	8.4	7.9
Qatar	1 359	2 169	120 527	131 758	15.4	7.5	85.1	86.2	0.3	0.5
Saudi Arabia	26 366	28 829	41 966	53 780	5.9	6.0	48.6	51.8	5.1	5.7
United Arab Emirates	6 799	9 346	70 785	58 042^{-1}	0.0	2.7	74.0	76.9	4.0	3.8
Yemen	21 704	24 407	4 250	3 958	3.8	-3.2	40.6	40.3	15.0	17.4
Mashreq plus Egypt and Sudan										
Egypt	75 492	82 056	9 596	11 085	5.7	2.0	43.9	42.9	8.7	12.7
Iraq	29 430	33 417	11 405	15 188	6.0	8.2	35.3	35.5	15.3	16.0
Jordan	5 786	6 460	10 478	11 782	5.0	2.7	36.6	36.3	12.7	12.6
Lebanon	4 186	4 467	13 614	17 170	9.1	1.7	43.2	44.4	7.2	6.5
Sudan	34 040	37 964	3 164	3 372	3.2	-6.5	45.3	45.4	14.8	15.2
Syria	20 346	–	–	–	–	–	40.1	–	10.9	–
West Bank & Gaza	3 597	4 170	3 422	4 921^{-1}	4.2	5.6	31.7	31.6	26.0	23.4
Maghreb										
Algeria	35 725	39 208	11 842	13 304	2.4	3.0	37.9	39.6	11.3	9.8
Libya	5 877	6 202	27 900	21 397	3.6	-11.6	43.2	42.6	19.1	19.6
Mauritania	3 423	3 890	2 631	3 042	2.2	5.9	36.3	37.2	31.2	31.0
Morocco	30 955	33 008	5 857	7 200	4.7	4.0	46.2	45.9	9.6	9.2
Tunisia	10 329	10 887	9 497	11 092	3.9	2.2	40.9	41.3	12.4	13.3

+*n*/-*n* = data refer to *n* years before or after reference year.

* For Kuwait, Oman and United Arab Emirates, the years are 2011–2012.

Note: Palestine is designated as the West Bank and Gaza here, owing to data coverage issues.

Source: World Bank's World Development Indicators, May 2015

The slump is hitting oil-rent economies hard

The slump in global oil prices from US$ 115 in June 2014 to US$ 47 in January 2015 has been mending holes in the budgets of Arab oil-importing countries such as Egypt, Jordan, Morocco and Tunisia. By contrast, it has punched holes in the budgets of oil-producing countries, including members of the Organization of Petroleum Exporting Countries (OPEC) [Figure 17.2]. The slump has not affected the export growth of Bahrain and the United Arab Emirates as much as that of other Gulf states, thanks to their diversification of exports. In order to diversify their own sources of income, other Arab governments will need to create a socio-economic environment in which all active stakeholders can thrive, including the private sector.

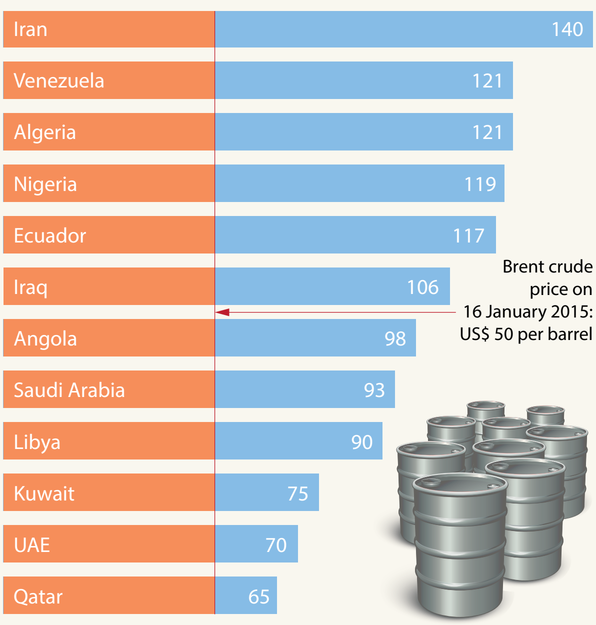
As early as 1986, the Gulf Cooperation Council identified economic diversification as a key strategic goal for its members. Whereas Saudi Arabia, the United Arab Emirates and Qatar have since developed their non-oil sectors, Bahrain and Kuwait are finding it harder to make the transition (Al-Soomi, 2012). Some voices from within the subregion have suggested transforming the Gulf Cooperation Council into a regional socio-economic and political bloc modelled on the European Union (O'Reilly, 2012).

The slump in oil prices comes at a particularly bad time for Iraq, which needs high oil revenue to revive its economy and combat terrorism, and for Libya which is facing internal instability and battling an insurgency by militia groups. Algeria raised its welfare spending in 2011 and now needs oil prices at US$ 121 a barrel to avoid a budget deficit, the International Monetary Fund estimates; it could slip into the red in 2015 for the first time in 15 years (*Wall Street Journal*, 2014). Oil and gas exports still represent two-thirds of national income for Algeria (see Figure 18.1), which has a tiny manufacturing sector (Figure 17.3). This said, Algeria may be less vulnerable the next time Brent crude prices tumble. It is developing solar and wind energy for domestic consumption and export (see p.447). Global investment in renewable energy technologies increased by 16% in 2014, triggered by an 80% decrease in the manufacturing costs of solar energy systems.

FDI flows to the Arab world have slowed

The economic fallout of the current upheaval has negatively affected the flow of FDI into Arab states, not to mention their tourism sector and real estate markets. Interestingly, the drop in FDI appears to have begun before 2011 (Figure 17.4). This can be traced back essentially to the global financial crisis of 2007–2008, thought to have been the worst since the Great Depression of the 1930s. Countries less affected by this turbulence, such as Algeria and Morocco, have seen greater stability in FDI inflows but they also enjoyed modest levels of foreign investment to begin with. There has been a surge in the flow of FDI to Morocco for new projects to expand the railways and deploy renewable energy on a massive scale. In Mauritania, FDI tends to be destined

Figure 17.2: **Estimated oil price needed to balance the government budget in OPEC member states, 2014**



Source: adapted from Wall Street Journal (2014), based on data from the Government of Libya, Angolan Ministry of Finance, International Monetary Fund, Arab Petroleum Investments Corp., Deutsche Bank

primarily for projects related to crude oil and natural gas exploration and drilling.

In Egypt, FDI increased by 7% to US$ 4.1 billion between 2013 and 2014. The Sharm El-Sheikh Economic Development Conference organized by the government in 2015 attracted more than 1 700 investors, as well as former British prime minister Tony Blair, US Secretary of State John Kerry and the International Monetary Fund's managing director Christine Lagarde. By the conference's end, Egypt had attracted US$ 36.2 billion in investment, plus US$ 18.6 billion in infrastructure contracts and US$ 5.2 billion in loans from international financial institutions.

STI GOVERNANCE ISSUES

Bringing the business community in from the cold

In March 2014, the Council of Ministers of Higher Education and Scientific Research in the Arab World adopted the *Arab Strategy for Science, Technology and Innovation* at its 14th congress in Riyadh (Saudi Arabia). The strategy has three main thrusts: academic training in science and engineering, scientific research and regional and international scientific co-operation. One of the strategy's key objectives is to involve the private sector more in regional and interdisciplinary collaboration, in order to add economic and development value to research and make better use of available expertise. Up to now, STI policies in Arab states have failed to catalyse knowledge production effectively or add value to products and services because they focus on developing R&D without taking the business community on board. There has also been a lot of talk about re-orienting the education system towards innovation and entrepreneurship but little action thus far (Box 17.2). Of note are the recent higher education reforms launched by Egypt and Tunisia.

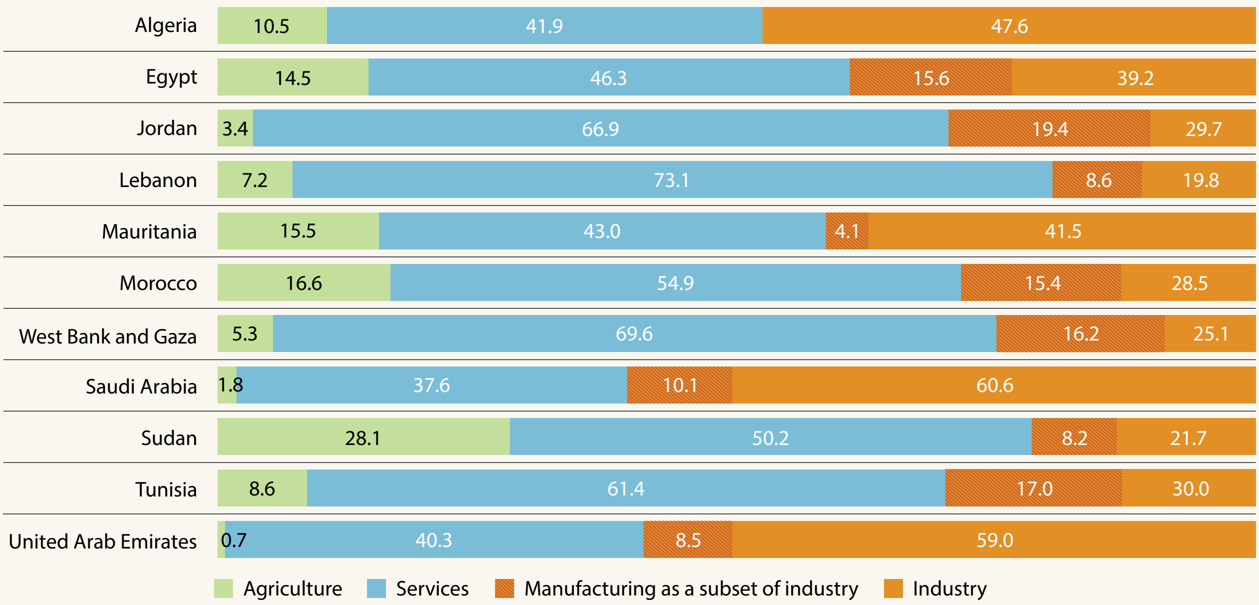
Tunisia and Saudi Arabia currently lead the Arab world in electronics and the United Arab Emirates is investing heavily in space technologies. In the field of renewable energy, Morocco is a leader in hydropower. Algeria, Jordan, Morocco and Tunisia are all developing solar energy. Egypt, Morocco and Tunisia have experience of wind energy that could benefit other countries keen to invest in this area, including Jordan, Libya, Saudi Arabia, Sudan and the United Arab Emirates. Morocco and Sudan are currently the main users of biomass.

The strategy proposes the following areas for co-operation:

- Development and management of water resources;
- Nuclear energy, with applications in the health sector, industry, agriculture, materials science, environment and nuclear energy production;
- Renewable energy: hydropower, solar, wind and biomass;

Figure 17.3: **GDP per economic sector in the Arab world, 2013 or closest year**

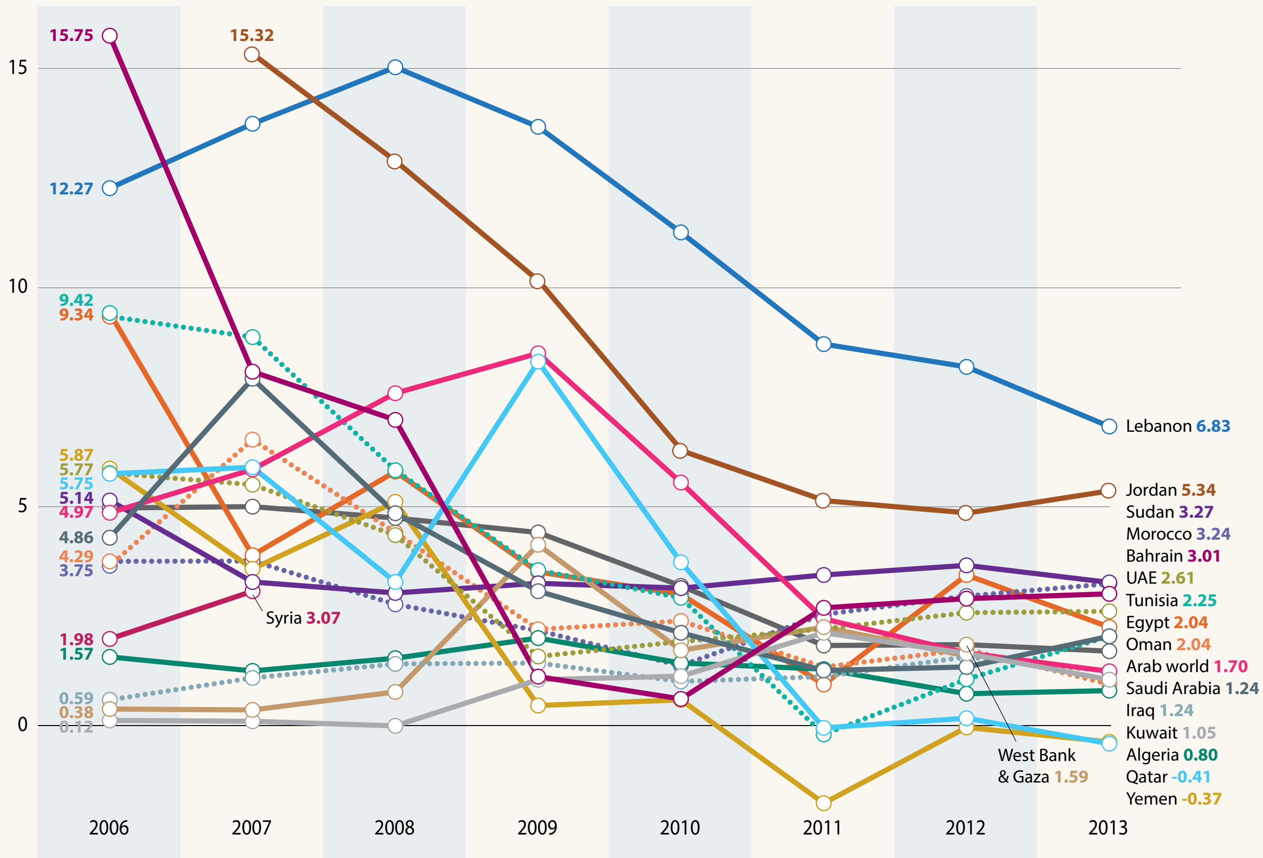
Selected economies



Note: For the West Bank and Gaza, data are for 2012. Palestine is designated as the West Bank and Gaza here, due to data coverage issues.

Source: World Bank's World Development Indicators, January 2015

Figure 17.4: **FDI inflow to selected Arab economies as a share of GDP, 2006–2013 (%)**



Source: World Bank's World Development Indicators, January 2015

- Oil, gas and petrochemicals industries;
- New materials;
- Electronics;
- Information technologies;
- Space sciences: applications in navigation systems, meteorology, irrigation, environmental monitoring, forest management, disaster risk management, urban planning, etc.;
- Nanotechnology: applications in health and pharmaceuticsal fields, food industry, environment, desalination, energy production, etc.;
- Agriculture, livestock and fisheries;
- Industry and production;
- Desertification, climate change and its impact on agriculture;
- Health sciences and biotechnology;
- Future convergent technologies: bioinformatics, nanobiotechnology, etc.

The strategy also emphasizes public outreach by scientists[5] and greater investment in higher education and training to build a critical mass of experts and staunch brain drain. It also advocates involving scientists from the diaspora. It was originally due to be adopted by ministers in 2011 but the timetable was perturbed by the events of 2011.

Priorities: problem-solving research, scientific mobility and education

In September 2013, ministers of research met in Morocco to lay the foundations for a common research policy between the five countries of the Maghreb and five countries of the Western Mediterranean: France, Italy, Malta, Portugal and Spain. These ten countries have met regularly since 1990 to discuss a wide range of issues, from security and economic co-operation to defence, migration, education and renewable energy but this was the first time that the 5+5 Dialogue, as

5. Tunisia's first dinosaur exhibition opened at Tunis Science City in mid-2011, with a focus on Saharan dinosaurs. The exhibition, which had taken two years to prepare, was originally scheduled to run until August 2012. It proved so popular that it was extended to mid-2013.

Box 17.2: **Matching university curricula to market needs**

The Network for the Expansion of Convergent Technologies in the Arab Region (NECTAR) was launched by the UNESCO Cairo Office in June 2011 to help correct the mismatch between the skills companies seek and the programmes provided by most universities.

Biotechnology, nanotechnology, ICTs and cognitive sciences are all convergent technologies which overlap considerably. By developing linkages between academia and industry in these fields, NECTAR plans to reorient academia towards problem-solving and remove the barriers between disciplines that currently hinder innovation in the Arab world.

A top priority for NECTAR has been to modernize the curricula of the Arab region's universities, in collaboration with renowned Arab scientists based at universities in the USA and in Egypt, where the majority of specialists in convergent technologies can be found in the Arab region. NECTAR targets both universities and technical colleges, as technicians are the group which gives convergent technologies their manufacturing edge.

The original plan was for professors from the USA to travel to Cairo to teach intensive courses (3-4 weeks maximum) every year. After the Arab Spring, Cairo and other key cities came to be considered a security risk, so the programme morphed into a virtual education programme. The e-content has been developed by Pennsylvania State University (PSU) and should be ready by August 2015. The courses will be permanently accessible via PSU's portal, with tutoring support on hand from the professors who own the courses. This approach will guarantee continuity and greater equity for Arab universities in terms of access to the coursework.

NECTAR has developed a virtual Higher Industrial Diploma Certificate and a master's degree in Applications of Nano-sciences. Initially, both programmes will be used to train university teaching staff (mainly PhD-holders). These staff members will then serve as the core team for the development of an undergraduate minor programme in nanosciences at each university. The tuition fees have been greatly reduced to encompass only PSU's costs in administering the programme. The diploma certificate will be accredited by PSU, whereas the master's programme will be accredited through participating universities in the Arab world.

There should be strong demand for NECTAR graduates from industries such as pharmaceuticals, chemicals, petrochemicals, oil production, opto-electronics, electronics, information technology, fertilizers, surface coating, building technology, foodstuffs and automotive.

NECTAR organized a regional forum in Cairo in November 2014 on the theme of Galvanizing Science Education and Higher Education towards a Knowledge-based Economy. Since the forum, UNESCO has submitted a proposal to the Egyptian government for a pilot education programme which would stretch from the first year of primary school to postgraduate levels.

Source: Nazar Hassan, UNESCO

the regional forum is known, had focused on research and innovation. In the *Rabat Declaration*, ministers undertake to facilitate training, technology transfer and scientific mobility by creating a specific visa for researchers; in parallel, the Maghreb countries are encouraged to join European research programmes as a first step towards harmonizing national policies and launching joint research projects.

The declaration adopted by ministers meeting in Rabat a year later at the Second[6] Forum on Science, Technology and Innovation in Africa reflects many of the concerns of the *Rabat Declaration:* the need for a greater focus on applied research to solve practical problems related to sanitation, health, agriculture, energy and climate change; the catalytic role of public investment in fostering a strong private sector; the need to improve the teaching of science, technology, engineering and mathematics and to facilitate the mobility of researchers.

Research takes a back seat in most universities

A growing number of Arab governments are setting up observatories to monitor their science systems, including in Egypt, Jordan, Lebanon, Palestine and Tunisia. When studying the data collected, however, analysts often see a direct correlation between the number of graduates or faculty and the number of researchers. This is misleading, as many students and faculty members do not conduct research and only a few actually publish in refereed journals listed by the Web of Science or Scopus and have international contacts. Many Arab universities are simply not research universities. Moreover, until recently, the terms of reference for a university professor in the Arab region did not include research.

The real test comes from counting the time spent effectively by an individual on research, as opposed to teaching or other tasks. It is rare for the actual research activity of teaching staff in government and most private universities to exceed 5–10% of their total academic duties, compared to 35–50% in European and American universities. A recent survey by the American University of Beirut shows that around 40% of academics' time is spent on research; this translates into an average of two publications per year for each full-time equivalent (FTE) researcher (ESCWA, 2014a).

In Jordan and many other Arab states, the bulk of scientific research is carried out within a higher education system that is faced with its own problems, including scarce resources and burgeoning student numbers. With the ranking craze sweeping Jordanian universities, rectors are no longer certain whether their institutions should aim to generate knowledge (i.e. scientific publications) or transmit knowledge (i.e. teach).

Scientists under pressure to target international journals

The pressure to publish in internationally recognized journals discourages publication in local journals. Moreover, Arab scientific journals suffer from fundamental problems, such as irregular periodicity and a lack of objective peer review. Many local periodicals are not regarded as credible vehicles for obtaining an academic promotion – even within the countries where they are published – thus reinforcing the desire of many academics to publish in international peer-reviewed journals whenever possible (ESCWA, 2014b).

In 2010, the Egyptian Academy of Scientific Research and Technology contacted a number of internationally renowned journals to establish a checklist of the criteria an article needed to meet to be accepted for publication. Five years on, there has been a 200% increase in peer-reviewed publications, according to the academy.

In 2014, UNESCO and the Arab League Educational, Cultural and Scientific Organization (ALECSO) decided to establish an online Arab observatory of science and technology. The observatory will host a portal for research projects and an inventory of Arab universities and scientific research centres, as well as patents, publications and master's and PhD theses in digital format; scientists will be able to use the forum to organize virtual conferences. The observatory will also host national observatories for Arab states to facilitate an interactive, semi-automated database of STI indicators.

Lessons can be learned from the Tunisian experience

Arab countries face a host of hurdles, including a lack of focus in research priorities and strategies, insufficient funding to meet research goals, little awareness of the importance of good scientific research, inadequate networking, limited collaborative efforts and brain drain. It is clear from available statistics that countries will need more sustained government support in future, if they are to strengthen university research, overcome weak university–industry linkages and give university graduates the professional and entrepreneurial skills to create viable national innovation systems.

There are lessons to be learned from the experience of Tunisia prior to December 2010 where, despite clear government support for research and higher education, socio-economic progress across the various strata of society had stalled and was failing to create jobs. This situation was at least in part a consequence of the lack of academic freedom and the fact that allegiance to the regime was considered more important than competence.

6. The first took place in Nairobi in March 2012. It focused on STI for youth employment, human capital development and inclusive growth. Both were organized by UNESCO, the Afrian Development Bank, United Nations Economic Commission for Africa and African Union in association with the Association for the Development of Education in Africa.

TRENDS IN R&D

Investment remains low but change is in the air

Gross domestic expenditure on research and development (GERD) as a percentage of GDP remains low in the Arab world. It is, of course, hard for wealthy oil-rent economies like the Gulf States to have a substantial GERD/GDP ratio, as GDP is so high. The countries with the greatest R&D intensity are Libya and Morocco (Figure 17.5). Tunisia used to have the Arab world's highest ratio but, after revising its national data, it published a GERD/GDP ratio of 0.71% in 2009 and 0.68% in 2012. The R&D intensity of Egypt, Jordan and Sudan has been low for decades, despite a growing number of public and private universities. That appears to be changing in Egypt, the only country for which there are recent data for this indicator: GERD reached an all-time high of 0.68% of GDP in 2013. Iraq, meanwhile, has failed to use the windfall of high oil prices in recent years to raise its own GERD/GDP ratio, which stood at about 0.03% in 2011. Most Arab States are still trailing fellow members of the Organization of Islamic Cooperation for this indicator, including Malaysia (1.07% in 2011) and Turkey (0.86% in 2011).

Although data on the type of R&D performed are only available for a handful of countries, they suggest a heavy focus on applied research in the Arab world. In 2011, Kuwait invested the entirety of GERD in applied research, compared to about two-thirds for Iraq and half for Qatar, according to the UNESCO Institute for Statistics. The remainder in Qatar was equally divided between basic research and experimental development. One-quarter of investment (26.6% in 2011) in Qatar went to medical and health sciences.

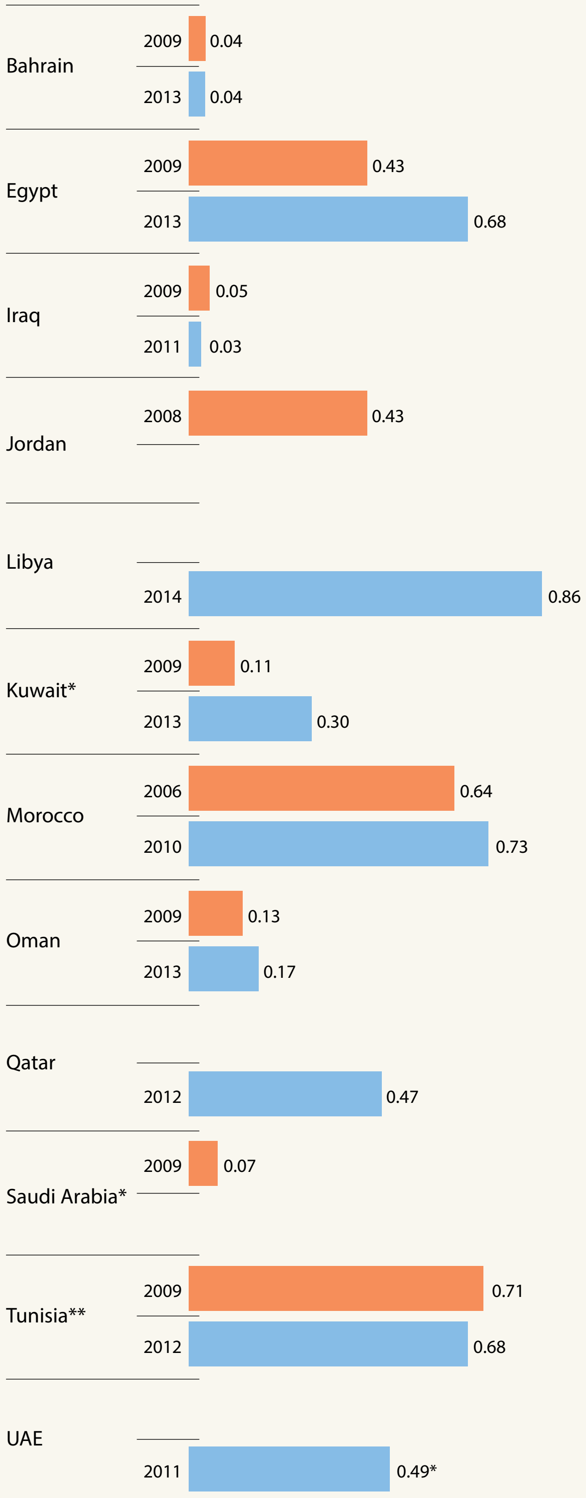
The greatest researcher density: Jordan, Morocco and Tunisia

In a context of rapid population growth, the number of researchers per million population is a more telling indicator of progress than sheer numbers. With 1 394 full-time equivalent (FTE) researchers per million inhabitants in 2012, Tunisia leads the Arab world for this category, followed by Morocco (Figure 17.6). Jordan has a density of researchers similar to that of Tunisia (1 913 in head counts) but this figure dates from 2008.

Egypt and Bahrain close to gender parity

Egypt (43% women) and Bahrain (41%) are relatively close to gender parity (Figure 17.7). In the majority of other countries for which data are available, women make up between one in three and one in five researchers. The notable exception is Saudi Arabia, where just 1.4% of researchers were women in 2009, although only the King Abdulaziz City for Science and Technology was surveyed. A number of countries have been building up their researcher intensity in recent years, albeit from low levels. Palestine is remarkable, in this respect. Thanks to the efforts of Palestinian universities, the government and the Palestine Academy of Science and Technology, 23% of researchers were women by 2013.

Figure 17.5: **GERD/GDP ratio in the Arab world, 2009 and 2013 or closest years (%)**



*estimation **based on national estimation

Note: Data are partial for Bahrain (higher education only), Kuwait (government sector only in 2009) and Saudi Arabia.

Source: UNESCO Institute for Statistics, January 2015; for Sudan: Noor (2012); for Oman: Al-Hiddabi (2014); for Libya: National Planning Council (2014) *National Strategy for Science, Technology and Innovation*

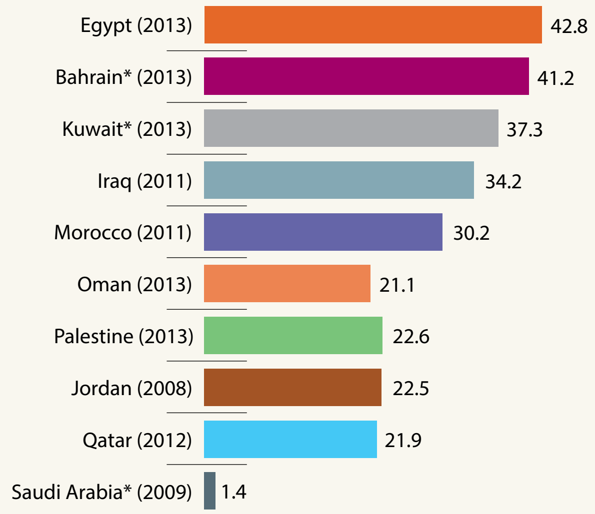
In several countries, women represent more than four out of ten researchers employed in natural sciences (Kuwait, Egypt and Iraq) and medical and health sciences (Kuwait, Egypt, Iraq, Jordan and Morocco). In Egypt, they have attained parity in social sciences and humanities. Most of the small group of Saudi women researchers works in medical and health sciences (Table 17.2).

The share of students graduating in S&T fields is relatively high, ranging from a low of 11% in Jordan to a high of 44% in Tunisia (Table 17.3). Recent data available for ten countries reveal that women represent between 34% and 56.8% of tertiary graduates in science, engineering and agriculture, a relatively high ratio (Table 17.4). In science and agriculture, women have achieved parity and even dominate these fields in most countries. They remain a minority in engineering, with the notable exception of Oman (Table 17.4).

Government expenditure on education represents a sizeable share of GDP in much of the Arab world. Moreover, most of the countries for which data are available devote more than 1% of GDP to higher education (Figure 17.8).

Figure 17.7: **Share of women Arab researchers, 2013 (%)**

Selected countries, in head counts



*partial data

Note: For Bahrain, data only cover the higher education sector; for Kuwait and Saudi Arabia, data only cover the government sector.

Source: UNESCO Institute for Statistics, January 2015

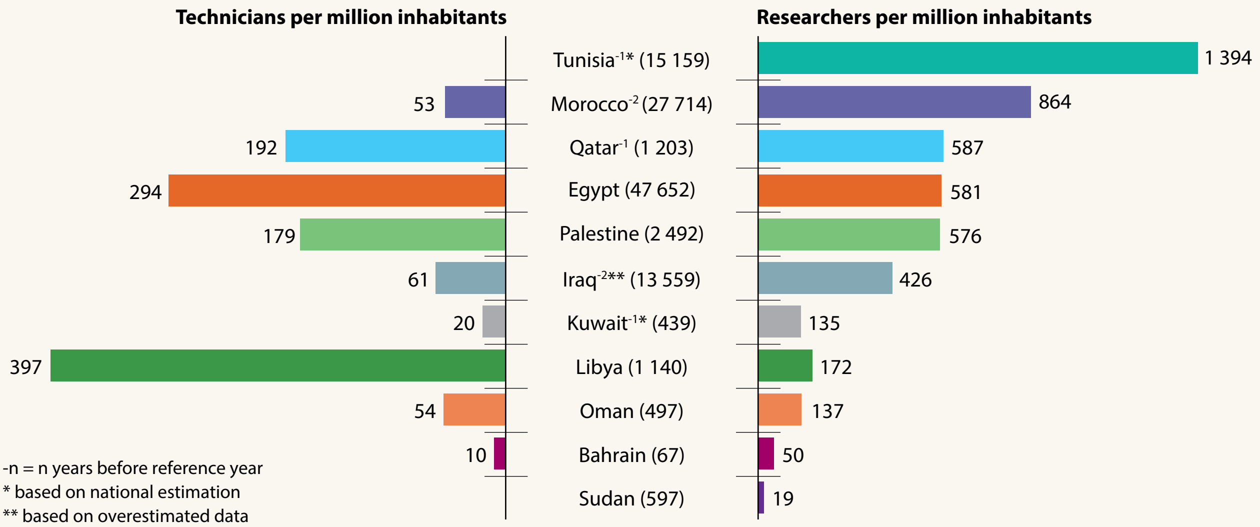
Little business R&D

In many Arab states, the bulk of GERD is performed by the government sector, followed by the higher education sector; the private sector assumes little or even no role in the research enterprise. In Egypt, for instance, the Academy of Scientific Research and Technology estimates that the private sector contributes only around 5% of the country's research expenditure (Bond *et al.*, 2012). Jordan, Morocco, Oman, Qatar, Tunisia and the United Arab Emirates are exceptions to the rule. Erawatch estimates that the private sector performs one-third of GERD in Jordan, 30% in Morocco (2010), 29% in the United Arab Emirates (2011), 26% in Qatar (2012) and 24% in Oman (2011). The figure is closer to 20% in Tunisia, according to the UNESCO Institute for Statistics. Business enterprises also finance about 24% of GERD in Qatar and 20% in Tunisia.

The data for FTE researchers by sector of employment and gender are scant for most Arab states. Available data for Egypt indicate that the majority of researchers were employed by

Figure 17.6: **Arab researchers and technicians (FTE) per million inhabitants, 2013 or closest year**

The total number of researchers is given in brackets



-n = n years before reference year
* based on national estimation
** based on overestimated data

Note: For Bahrain, data only cover the higher education sector; for Kuwait, data only cover the government sector. Data are also partial for Moroccan technicians.

Source: UNESCO Institute for Statistics, January 2015; for Libya: Libyan Authority for Research, Science and Technology; for Sudan: National Research Centre

Table 17.2: **Arab researchers (HC) by field of employment, 2013 or closest year (%)**

Selected economies

	Year	Natural sciences		Engineering and technology		Medical and health sciences		Agricultural sciences		Social sciences		Humanities		Unclassified	
		Total	Women	Total	Women	Total	Women	Total	Female	Total	Women	Total	Women	Total	Women
Gulf States plus Yemen															
Kuwait	2013	14.3	41.8	13.4	29.9	11.9	44.9	5.2	43.8	8.8	33.4	13.3	35.6	33.2	36.5
Oman	2013	15.5	13.0	13.0	6.2	6.5	30.0	25.3	27.6	24.3	23.7	13.2	22.1	2.2	33.3
Qatar	2012	9.3	21.7	42.7	12.5	26.0	27.8	1.6	17.9	14.3	34.6	4.8	33.7	1.3	31.8
Saudi Arabia*	2009	16.8	2.3	43.0	2.0	0.7	22.2	2.6	–	0.0	–	0.5	–	36.4	–
Mashreq and Egypt															
Egypt	2013	8.1	40.7	7.2	17.7	31.8	45.9	4.1	27.9	16.8	51.2	11.4	47.5	20.6	41.0
Iraq	2011	17.7	43.6	18.9	25.7	12.4	41.4	9.4	26.1	32.3	35.7	9.3	26.7	0.0	28.6
Jordan	2008	8.2	25.7	18.8	18.4	12.6	44.1	2.9	18.7	4.0	29.0	18.1	32.3	35.3	10.9
Palestine	2013	16.5	–	10.9	–	5.8	–	4.8	–	27.7	–	34.2	–	0	
Maghreb															
Libya	2013	14.3	15.0	17.0	18	24.4	0.1	11.5	0.1	2.0	20.0	12.4	20.0	32.4	20.0
Morocco	2011	33.7	31.5	7.6	26.3	10.4	44.1	1.8	20.5	26.1	26.6	20.4	27.8	0	0

* government researchers only

Note: For Bahrain, data only cover the higher education sector. For Egypt, the distribution of researchers is only available for the higher education sector; data related to the government sector are 'unclassified.'

Source: UNESCO Institute for Statistics (UIS), June, 2015; for Libya: Libyan Authority for Research, Science and Technology

Table 17.3: **Arab tertiary graduates in science, engineering and agriculture, 2012 or closest year**

	Year	Total (all fields)	Science, engineering and agriculture		Science			Engineering, manufacturing and construction			Agriculture		
			Number	Share of total (%)	Number	Share of science, engineering and agriculture (%)	Share of total (%)	Number	Share of science, engineering and agriculture (%)	Share of total (%)	Number	Share of science, engineering and agriculture (%)	Share of total (%)
Algeria	2013	255 435	62 356	24.4	25 581	41.0	10.0	32 861	52.7	12.9	3 914	6.3	1.5
Egypt	2013	510 363	71 753	14.1	21 446	29.9	4.2	38 730	54.0	7.6	11 577	16.1	2.3
Jordan	2011	60 686	7 225	11.9	3 258	45.1	5.4	2 145	29.7	3.5	1 822	25.2	3.0
Lebanon	2011	34 007	8 108	23.8	3 739	46.1	11.0	4 201	51.8	12.4	168	2.1	0.5
Morocco	2010	75 744	27 524	36.3	17 046	61.9	22.5	9 393	34.1	12.4	1 085	3.9	1.4
Palestine	2013	35 279	5 568	15.8	2 832	50.9	8.0	2 566	46.1	7.3	170	3.1	0.5
Qatar	2013	2 284	671	29.4	119	17.7	5.2	552	82.3	24.2	0	0.0	0.0
Saudi Arabia	2013	141 196	39 312	27.8	25 672	65.3	18.2	13 187	33.5	9.3	453	1.2	0.3
Sudan	2013	124 494	23 287	18.7	12 353	53.0	9.9	7 891	33.9	6.3	3 043	13.1	2.4
Syria	2013	58 694	12 239	20.9	4 430	36.2	7.5	6 064	49.5	10.3	1 745	14.3	3.0
Tunisia	2013	65 421	29 272	44.7	17 225	58.8	26.3	11 141	38.1	17.0	906	3.1	1.4
UAE	2013	25 682	5 866	22.8	2 087	35.6	8.1	3 742	63.8	14.6	37	0.6	0.1

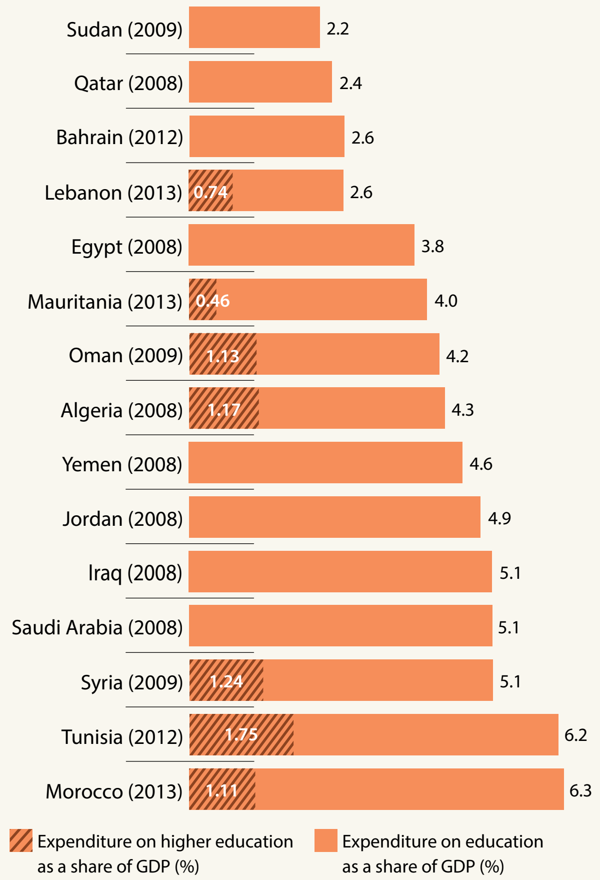
Source: UNESCO Institute for Statistics, July 2015

Table 17.4: **Share of Arab female graduates in science, engineering and agriculture, 2014 or closest year (%)**

Country	Year	Science	Engineering	Agriculture	Science, engineering and agriculture
Bahrain	2014	66.3	27.6	0.0	42.6
Jordan	2011	65.2	13.4	73.4	51.9
Lebanon	2011	61.5	26.9	58.9	43.5
Oman	2013	75.1	52.7	6.0	56.8
Palestine	2013	58.5	31.3	37.1	45.3
Qatar	2013	64.7	27.4	0.0	34.0
Saudi Arabia	2013	57.2	3.4	29.6	38.8
Sudan	2013	41.8	31.8	64.3	41.4
Tunisia	2013	63.8	41.1	69.9	55.4
UAE	2013	60.2	31.1	54.1	41.6

Source: UNESCO Institute for Statistics, July 2015

Figure 17.8: **Arab government expenditure on education as a share of GDP (%)**



Source: UNESCO Institute for Statistics, July 2015; for Iraq and Jordan: UNDP (2009) *Arab Knowledge Report,* Table 5-4, p. 193.

the higher education sector (54%) in 2013 and the remainder by government (46%), although the business sector was not surveyed (ASRT, 2014). In Iraq, as many as eight out of ten (83%) researchers are working in academia.

In Egypt, medical and health sciences occupy the greatest number of researchers, a reflection of the country's priorities. In Kuwait and Morocco, the majority of researchers are working in the natural sciences (Table 17.2). In Oman in 2011, the majority of researchers were social scientists, whereas Qatari researchers tend to be most numerous in engineering and technology. Interestingly, one-third of Palestinian researchers worked in the humanities in 2011, the highest ratio among Arab states.

Morocco leads for high-tech exports, Qatar and Saudi Arabia for publications

Given the modest role played by the private sector in the Arab world, it is hardly surprising that the share of high-tech products in manufactured exports is low, particularly for Gulf states (Figure 17.9). Morocco tops the region for high-tech exports and comes second only to Egypt for patents (Table 17.5).

Interestingly, two oil-rent economies published the most scientific articles per million inhabitants in 2014. Along with Egypt, their output has also grown faster than that of any other country in recent years. Qatar and Saudi Arabia also have the region's highest citation rate (Figure 17.10).

Two-thirds of articles produced by scientists in the Arab world between 2008 and 2014 were co-authored with international partners. Egypt, Saudi Arabia and the USA tend to be the closest collaborators but Chinese scientists have also become a key partner for Iraq, Qatar and Saudi Arabia (Figure 17.10). It is worth noting that the Thomson Reuters selection of Highly Cited Researchers of 2014[7] lists only three Arab scientists whose 'first' affiliation is with a university in the Arab world. They are Prof. Ali H. Nayfeh (University of Jordan and Virginia Tech), Prof. Shaher El-Momani (University of Jordan and King Abdulaziz University in Saudi Arabia) and Prof. Salim Messaoudi (Algeria), a faculty member of King Fahd University of Petroleum and Minerals in Saudi Arabia.

7. http://highlycited.com/archive_june.htm

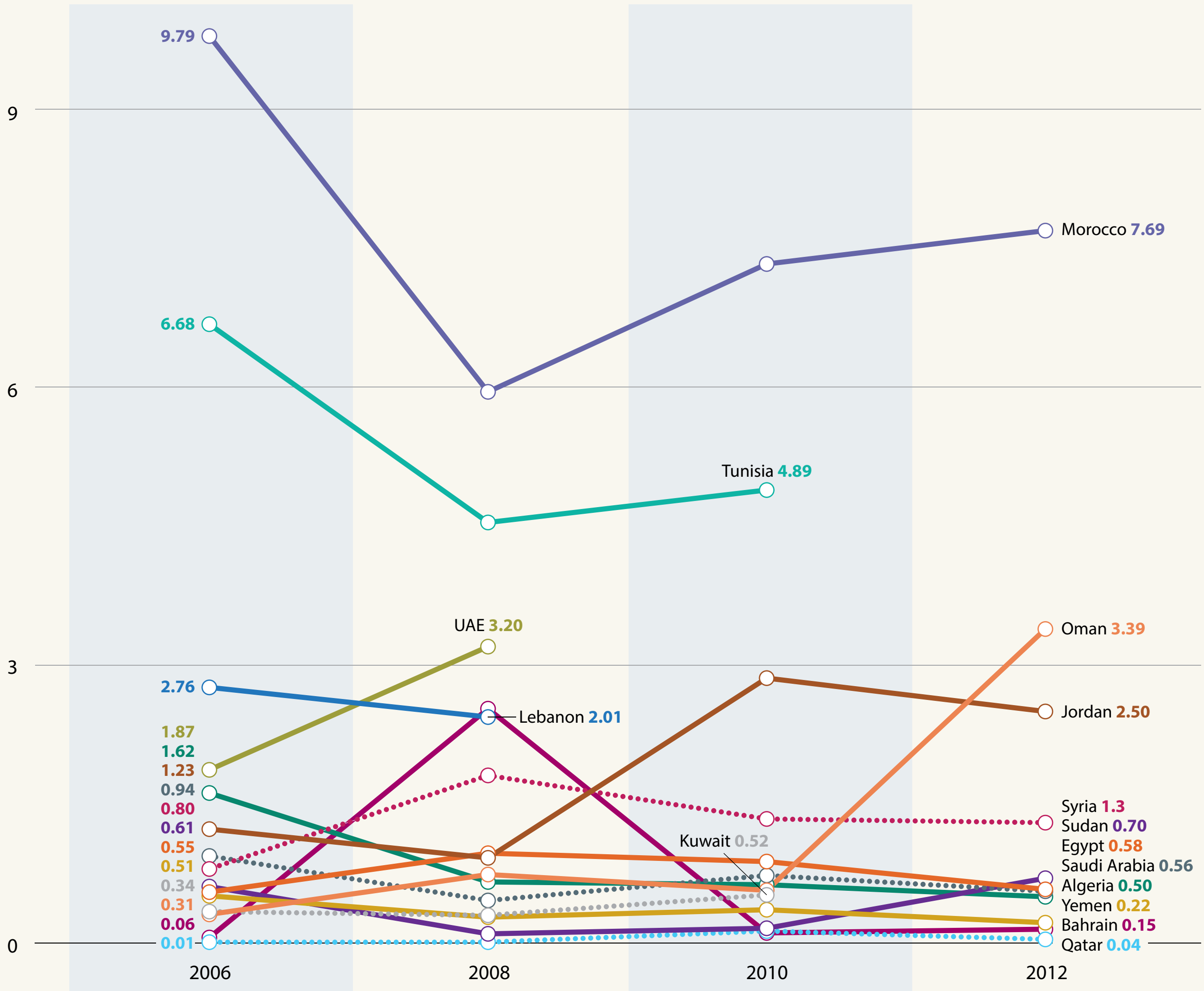
Table 17.5: **Patent applications in Arab states, 2010–2012**

	Patent applications residents			Patent applications non-residents			Total patent applications		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Egypt	605	618	683	1 625	1 591	1 528	2 230	2 209	2 211
Morocco	152	169	197	882	880	843	1034	1 049	1 040
Saudi Arabia	288	347		643	643		931	990	
Algeria	76	94	119	730	803	781	806	897	900
Tunisia	113	137	150	508	543	476	621	680	626
Jordan	45	40	48	429	360	346	474	400	394
Yemen	20	7	36	55	37	49	75	44	85
Lebanon	0	0	0	13	2	2	13	2	2
Sudan	0	0	0	0	1	0	0	0	0
Syria	0	0	0	1	0	0	1	0	0

Source: WIPO statistics database, December 2014; Thomson Reuters' Web of Science, data treatment by Science-Metrix

Figure 17.9: **High-tech exports from the Arab world, 2006, 2008, 2010 and 2012**

As a share of manufactured exports (%)

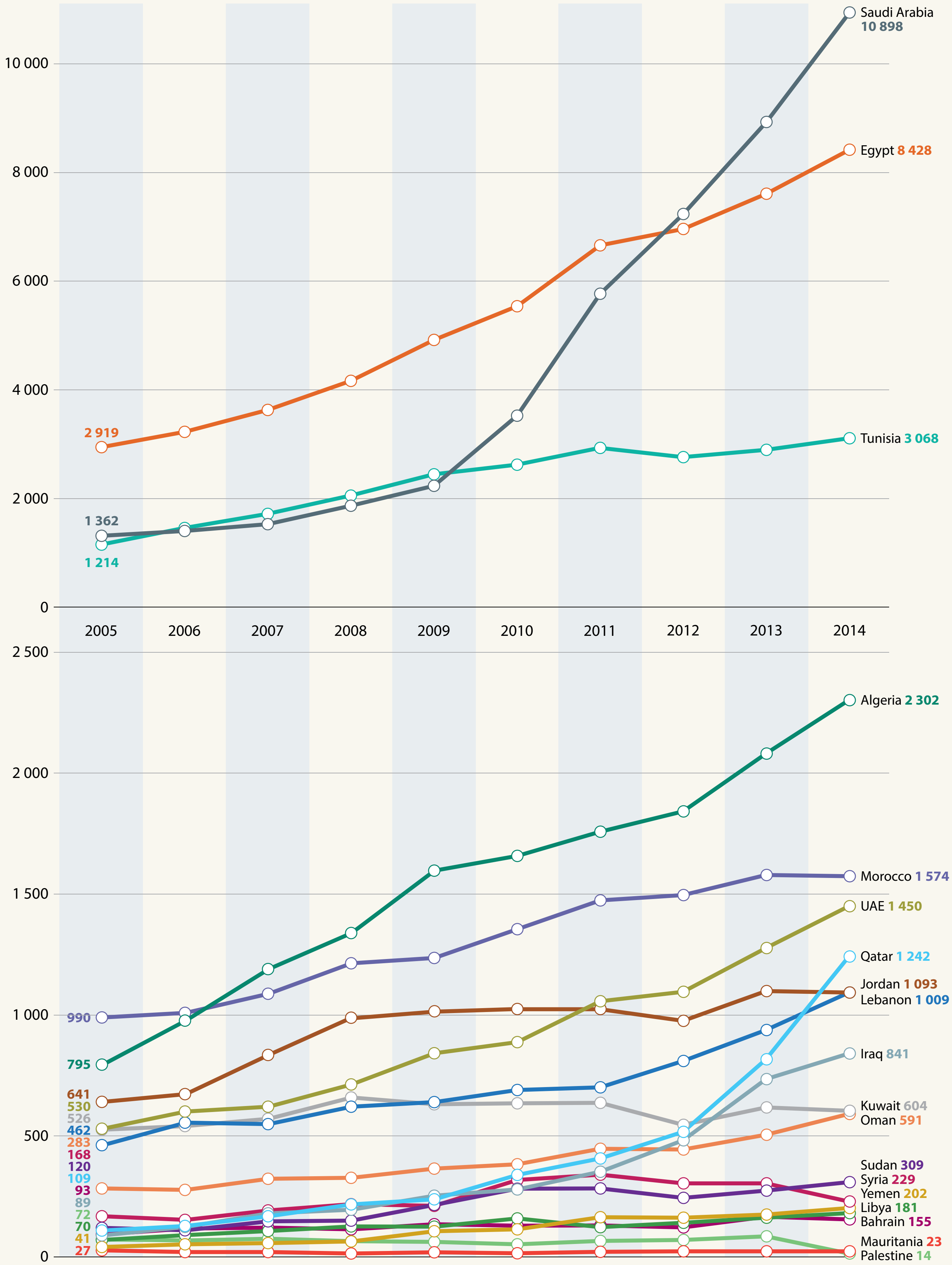


Source: United Nations Statistics Division, July 2014

Chapter 17

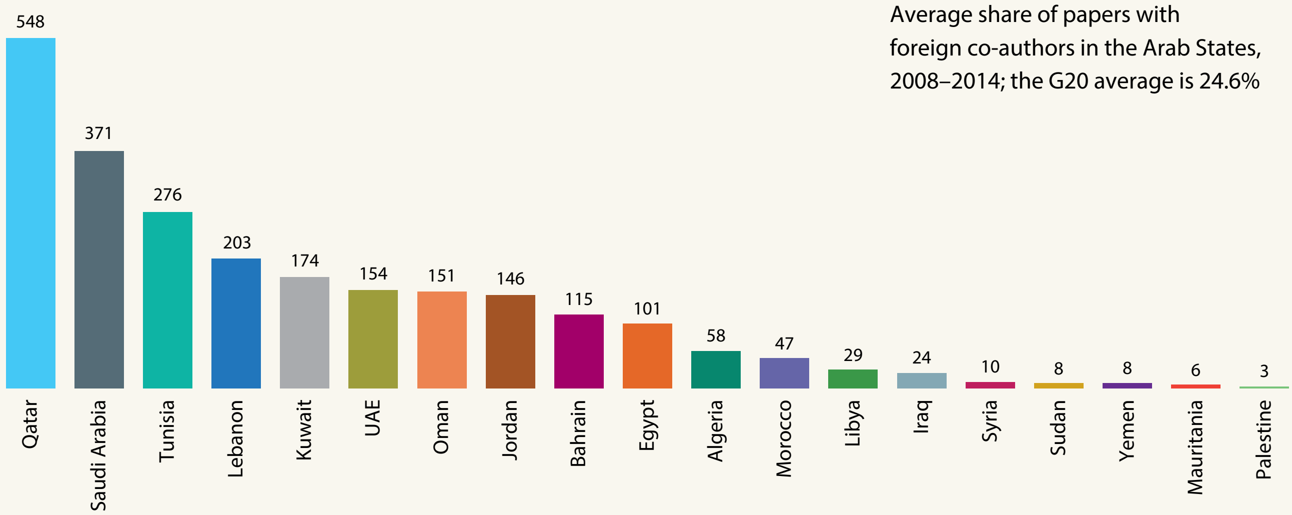
Figure 17.10: **Scientific publication trends in the Arab States, 2005–2014**

Strong growth in Saudi Arabia, Egypt and Qatar



Qatar, Saudi Arabia and Tunisia have the highest publication intensity

Publications per million inhabitants in 2014

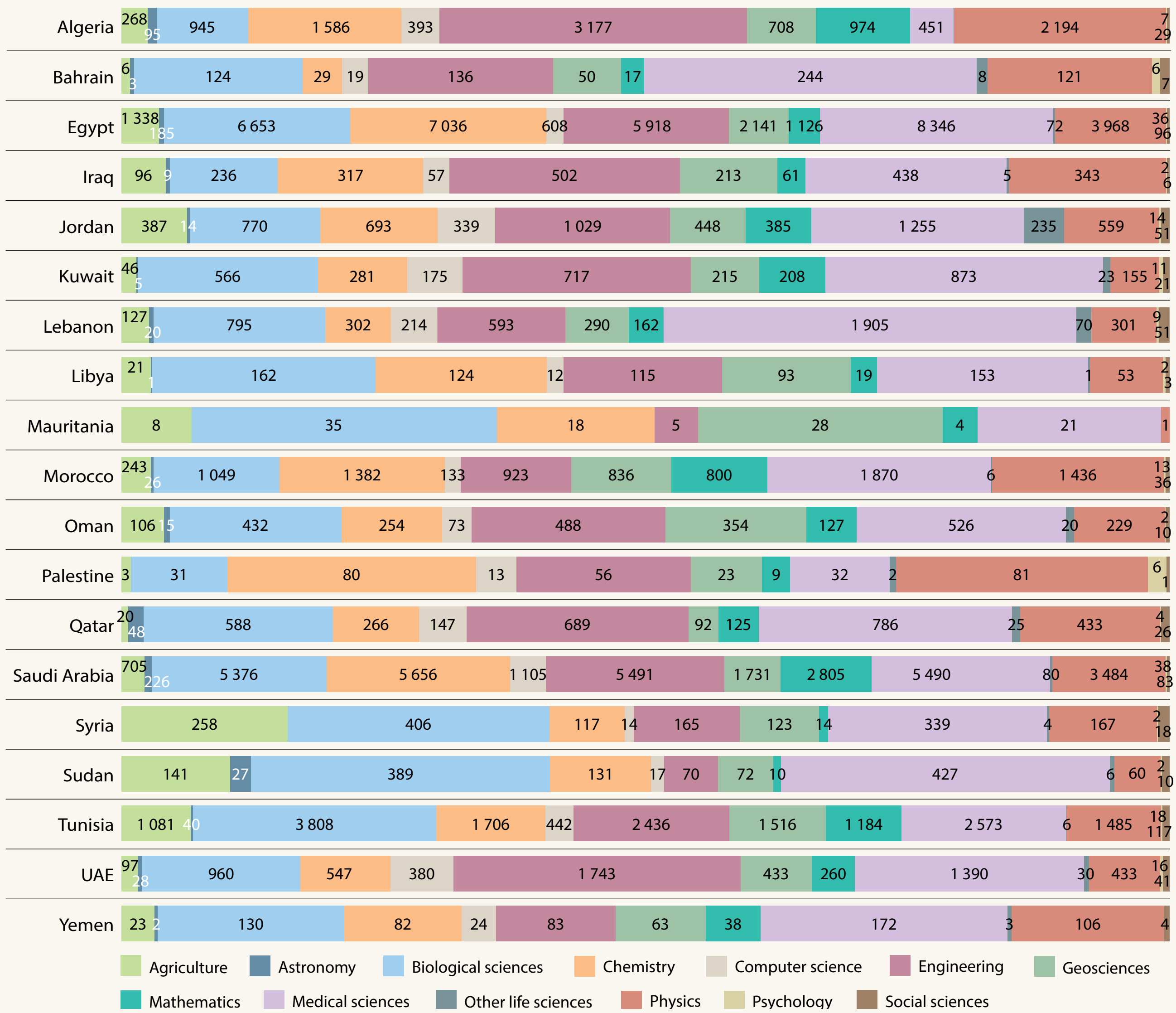


67.2%

Average share of papers with foreign co-authors in the Arab States, 2008–2014; the G20 average is 24.6%

The Arab States publish most in life sciences, followed by engineering and chemistry

Cumulative totals by field, 2008–2014



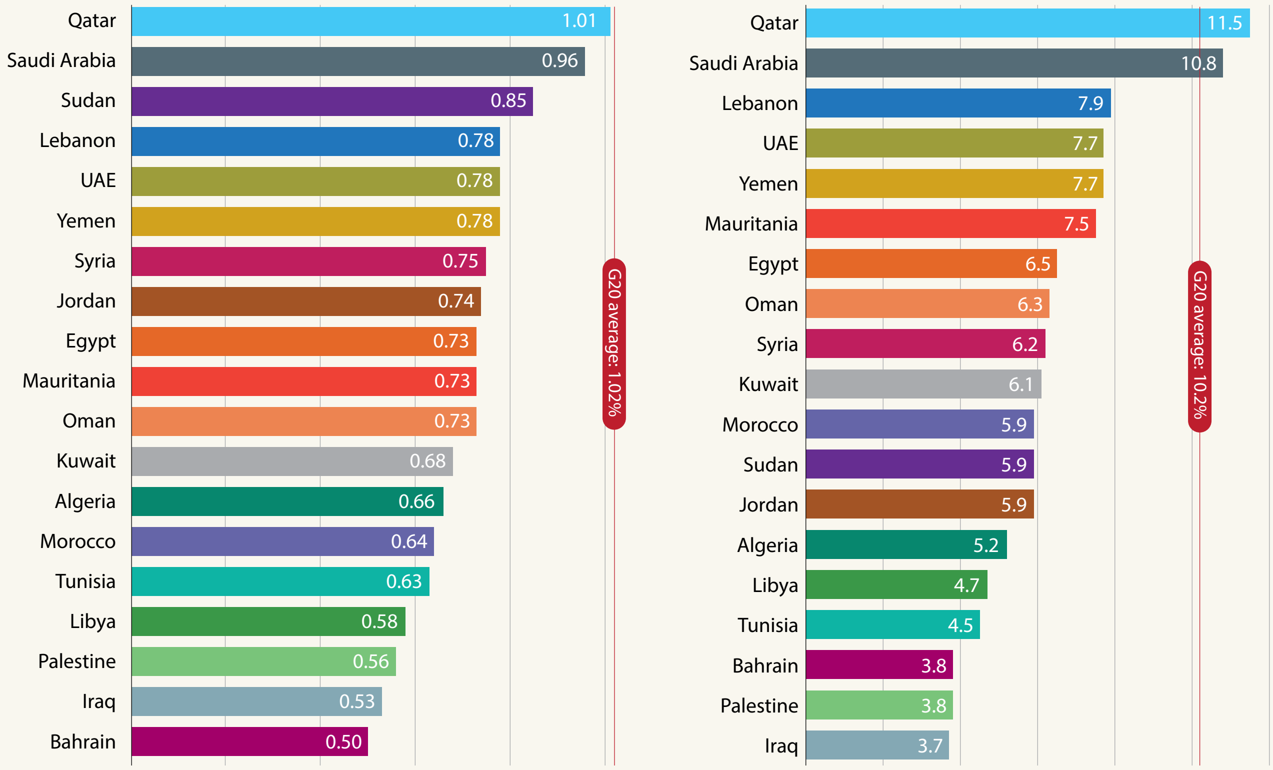
Note: The totals do not include unclassified publications, which make up a sizeable share in some cases: Saudi Arabia (8 264), Egypt (6 716), Tunisia (2 275), Algeria (1 747), Jordan (1 047), Kuwait (1 034) and Palestine (77).

Figure 17.10 *(continued)*

Qatar and Saudi Arabia have the highest citation rate

Average citation rate for publications, 2008–2012

Share of papers among 10% most-cited, 2008–2012 (%)



China has become a key collaborator for Iraq, Qatar and Saudi Arabia

Main foreign partners, 2008–2014

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Algeria	France (4 883)	Saudi Arabia (524)	Spain (440)	USA (383)	Italy (347)
Bahrain	Saudi Arabia (137)	Egypt (101)	UK (93)	USA (89)	Tunisia (75)
Egypt	Saudi Arabia (7 803)	USA (4 725)	Germany (2 762)	UK (2 162)	Japan (1 755)
Iraq	Malaysia (595)	UK (281)	USA (279)	China (133)	Germany (128)
Jordan	USA (1 153)	Germany (586)	Saudi Arabia (490)	UK (450)	Canada (259)
Kuwait	USA (566)	Egypt (332)	UK (271)	Canada (198)	Saudi Arabia (185)
Lebanon	USA (1 307)	France (1277)	Italy (412)	UK (337)	Canada (336)
Libya	UK (184)	Egypt (166)	India (99)	Malaysia (79)	France (78)
Mauritania	France (62)	Senegal (40)	USA (18)	Spain (16)	Tunisia (15)
Morocco	France (3 465)	Spain (1 338)	USA (833)	Italy (777)	Germany (752)
Oman	USA (333)	UK (326)	India (309)	Germany (212)	Malaysia (200)
Palestine	Egypt (50)	Germany (48)	USA (35)	Malaysia (26)	UK (23)
Qatar	USA (1 168)	UK (586)	China (457)	France (397)	Germany (373)
Saudi Arabia	Egypt (7 803)	USA (5 794)	UK (2 568)	China (2 469)	India (2 455)
Sudan	Saudi Arabia (213)	Germany (193)	UK (191)	USA (185)	Malaysia (146)
Syria	France (193)	UK (179)	Germany (175)	USA (170)	Italy (92)
Tunisia	France (5 951)	Spain (833)	Italy (727)	Saudi Arabia (600)	USA (544)
United Arab Emirates	USA (1 505)	UK (697)	Canada (641)	Germany (389)	Egypt (370)
Yemen	Malaysia (255)	Egypt (183)	Saudi Arabia (158)	USA (106)	Germany (72)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

ALGERIA

Diversifying the national energy mix

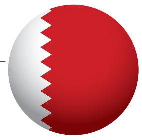
In 2008, Algeria adopted a plan to optimize its national innovation system. Piloted by the Ministry of Higher Education and Scientific Research (MoHESR), the plan proposed a reorganization of science, coupled with the development of infrastructure, human resources and research, as well as greater scientific co-operation and funding. Algeria devoted just 0.07% of GDP to GERD in 2005; although these data are partial, they suggest an extremely low R&D intensity in the years prior to the plan's adoption.

The National Commission for the Evaluation of Permanent Researchers was launched in 2000 to give scientists a boost by allocating more financial resources to research and introducing incentives for them to make better use of the results of their research. The aim was also to enhance collaboration with the Algerian diaspora. The commission met for the 12th time in February 2012. More recently, MoHESR has announced plans to establish a national academy of sciences in 2015.

Algerian scientists published most in engineering and physics between 2008 and 2014. Their output has progressed steadily, doubling between 2005 and 2009 then again between 2010 and 2014 (Figure 17.10). Over the seven years to 2014, 59% of Algerian scientific papers had foreign co-authors.

Although Algeria is Africa's third-biggest oil producer (see Figure 19.1) and the world's tenth-biggest producer of natural gas, the country's known gas reserves could be exhausted within half a century, according to British Petroleum's *Statistical Review of World Energy* in 2009 (Salacanin, 2015). Like its neighbours Morocco and Tunisia, Algeria is diversifying its energy mix. Sixty solar and wind projects have been approved within the country's Renewable Energy and Energy Efficiency Programme, which was adopted in March 2011 and revised in 2015. The aim is for 40% of electricity for national consumption to be produced using renewable energy sources by 2030. Up to 22 000 MW of power-generating capacity from renewable sources will be installed between 2011 and 2030, 12 000 MW to meet domestic demand and 10 000 MW destined for export. In July 2013, Algeria signed a memorandum of understanding with the EU in the field of energy which includes provisions for the transfer of technology to Algeria for both fossil fuels and renewable energy.

BAHRAIN



A need to reduce dependency on oil

Bahrain has the smallest hydrocarbon reserves of any Gulf state, producing just 48 000 barrels per day from its one onshore field (Salacanin, 2015). The bulk of the country's revenue comes from its share of the offshore field administered by Saudi Arabia. The gas reserve in Bahrain is expected to last for less than 27 years, leaving the country with few sources of capital to pursue the development of new industries.

The *Bahraini Economic Vision 2030* does not indicate how the stated goal of shifting from an economy built on oil wealth to a productive, globally competitive economy will be attained.

Apart from the Ministry of Education and the Higher Education Council, the two main hives of activity in STI are the University of Bahrain and the Bahrain Centre for Strategic, International and Energy Studies. The latter was founded in 2009 to undertake research with a focus on strategic security and energy issues to encourage new thinking and influence policy-making.

The University of Bahrain was established in 1986. It has over 20 000 students, 65% of whom are women, and around 900 faculty members, 40% of whom are women. From 1986 to 2014, university staff published 5 500 papers and books. The university spends about US$ 11 million per year on research, which is conducted by a contingent of 172 men and 128 women.

New infrastructure for science and education

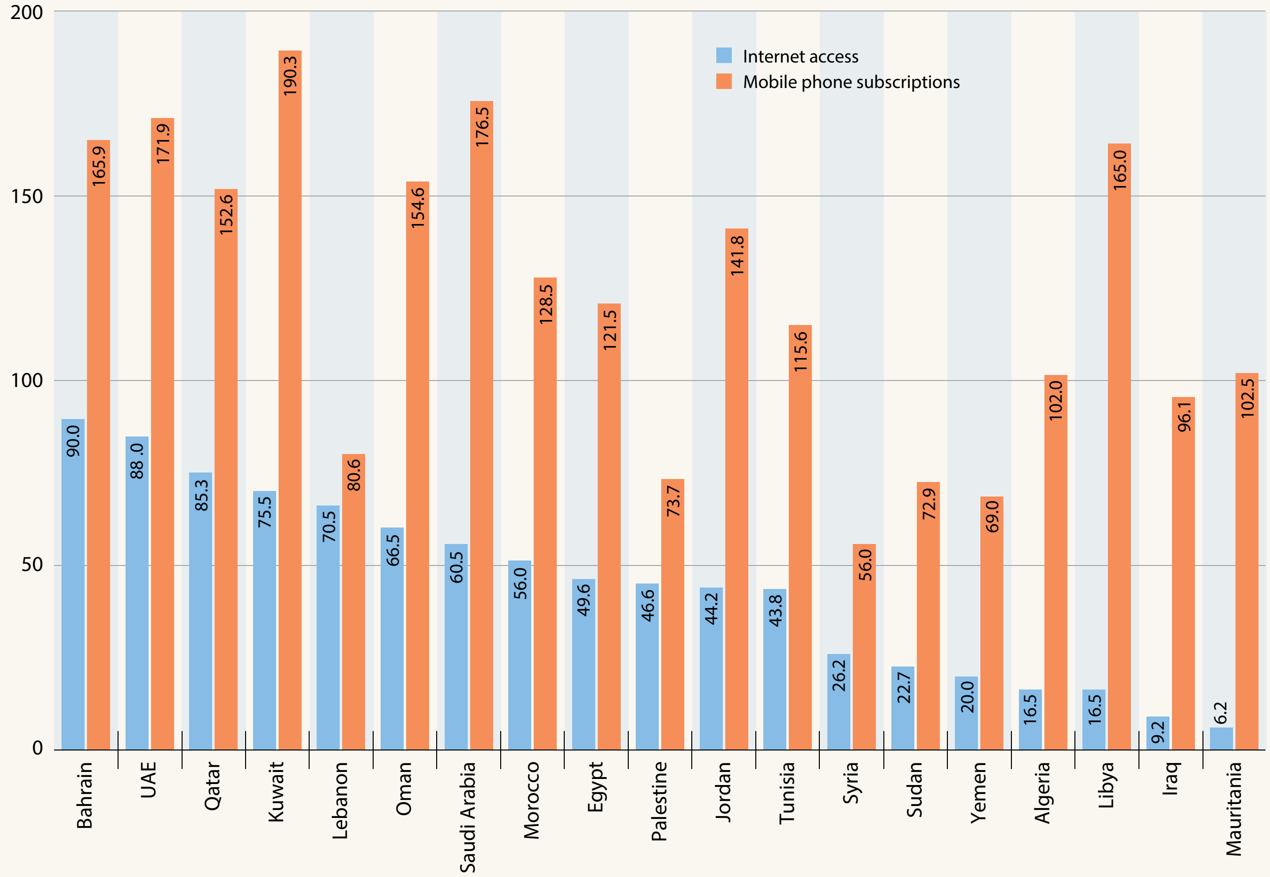
In November 2008, an agreement was signed by the Bahraini government and UNESCO to establish a Regional Centre for Information and Communication Technology in Manama under the auspices of UNESCO. The aim is to establish a knowledge hub for the six member states of the Gulf Cooperation Council. In March 2012, the centre hosted two high-level workshops on ICTs and education.

In 2013, the Bahrain Science Centre was launched as an interactive educational facility targeting 6–18-year olds. The topics covered by current exhibitions include junior engineering, human health, the five senses, Earth sciences and biodiversity.

In April 2014, Bahrain launched its National Space Science Agency. The agency is working to ratify international space-related agreements such as the Outer Space Treaty, the Rescue Agreement, the Space Liability Convention, the Registration Convention and the Moon Agreement. The agency will be establishing sound infrastructure for the observation of outer space and the Earth. It also hopes to

Figure 17.11: **Internet access and mobile phone subscriptions in Arab states, 2013**

Per 100 inhabitants



Source: International Telecommunications Union, February 2015

build a science culture within the kingdom and encourage technological innovation, among other goals.

Bahrain tops the Arab world for internet penetration, trailed by the United Arab Emirates and Qatar (Figure 17.11). Internet access has gone up tremendously in all Gulf States. Just half of Bahrainis and Qataris (53%) and two-thirds of those in the United Arab Emirates (64%) had access in 2009, compared to more than 85% in 2013. At the other end of the scale, fewer than one person in ten had internet access in Iraq and Mauritania in 2013.

EGYPT

Revolutionary fervour has spilled over into science

Current national policy documents in Egypt all consider science and technology to be vital for the country's future. The Constitution adopted in 2014 mandates the state to allocate 1% of GDP to R&D and stipulates that the 'state guarantees the freedom of scientific research and encourages its institutions as a means towards achieving national sovereignty and building a knowledge economy that supports researchers and inventors (Article 23).[8]

For decades, science and technology in Egypt were highly centralized and dominated by the public sector. R&D was carried out mostly by state-run universities and research centres supervised by the Ministry of Higher Education and Scientific Research, which split into the Ministry of Higher Education and the Ministry of Scientific Research (MoSR) in 2014. Egypt's research centres used to be scattered across different ministries but they are currently being reorganized under the umbrella of the Supreme Council of Scientific Research Centres and Institutes, in order to improve co-ordination.

The *UNESCO Science Report 2010* had recommended that Arab states establish national STI observatories. The Egyptian Science, Technology and Innovation Observatory was launched in February 2014 to provide advice on policy-making strategies and resource allocation through data collection and reporting on the development of national S&T capacities. The observatory is hosted by Egypt's Academy

8. See: http://stiiraqdev.wordpress.com/2014/03/15/sti-constitutions-arab-countries/

of Scientific Research and Technology. It published its first data collection in 2014 (ASRT, 2014). The observatory did not collect data for the business enterprise sector but nevertheless reported a rise in GERD from 0.43% to 0.68% of GDP between 2009 and 2013. The observatory also reports 22 000 FTE researchers in government research institutes and 26 000 at public universities. Just over half of Egypt's 42 universities (24) are public institutions but these also account for three-quarters of university enrolment.

A reform to produce market-ready graduates

Public expenditure on higher education stands at the acceptable level of 1% of GDP, compared to an average of 1.4% for OECD countries. This corresponds to 26% of the total public spending on education, close to the OECD average of 24%. Nonetheless, most of these resources cover administrative costs, in particular the salaries of academic and non-academic staff, rather than going on educational programmes. This practice has created a legacy of outdated equipment, infrastructure and learning materials. The amount spent on each student averages just US$ 902 (23% of GDP per capita), just one-tenth of the US$ 9 984 (37% of GDP per capita) spent on each student in OECD countries.

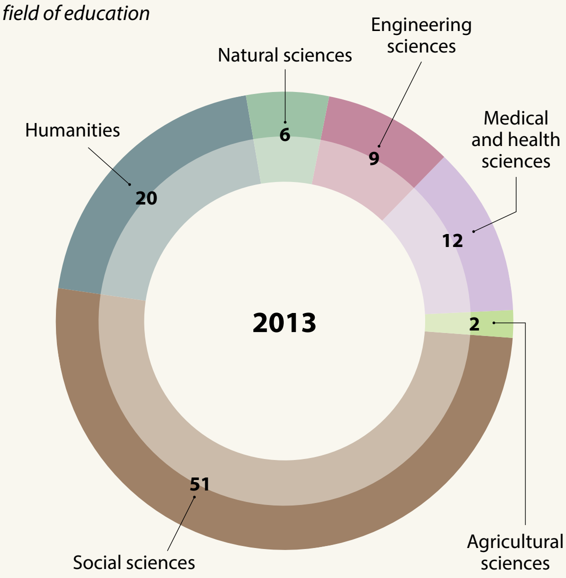
Universities offer a minimum degree course of four years and there tends to be a high ratio of students to staff, especially in humanities and social sciences which attract seven out of ten Egyptian students (Figure 17.12). The proportion of female university graduates in tertiary education has inched closer to gender parity in recent years but only in urban areas. The urban–rural gender divide is still alive and well.

Technical colleges offer a two-year programme of study in a number of specializations, including manufacturing, agriculture, commerce and tourism. A few technical colleges provide five-year courses leading to advanced diplomas but these technical diplomas lack the social status of university degrees. Whereas 60% of secondary school pupils are channelled towards technical and vocational secondary schools, almost 95% of enrolment in post-secondary technical colleges comes from general secondary schools; this leaves many pupils from technical and vocational secondary schools with no prospects for further education.

The government has announced a US$ 5.87 billion reform plan for higher education to produce market-ready graduates able to contribute to a knowledge economy. The plan runs from 2014 to 2022 and will be implemented in two phases. The plan is financed by the new constitutional entitlements that require the state to allocate at least 4% of the budget to education, 2% to higher education and 1% to scientific research (Articles 19–21 of the 2014 Constitution); it will also entail legislative reform to improve governance mechanisms.

Figure 17.12: **Egyptian student enrolment in public universities, 2013 (%)**

By field of education



Source: ASRT (2014)

A stronger focus on technical and vocational education

The plan aims to improve access to technical education within universities, ensure quality assurance, raise the level of educational services, link the output of the higher education system with labour market requirements and make universities more international. Recently, the government has begun preparing for the introduction of preferential admission criteria for promising students. This should improve the flexibility of their academic pathways.

Zewail City of Science and Technology revived

The Nile University is Egypt's first research university. Founded in 2006 by the non-profit Egyptian Foundation for Technology Education, this private institution was built on the outskirts of Cairo on land gifted by the government. In May 2011, the caretaker government reassigned the land and buildings to the Zewail City of Science and Technology and declared the complex a National Project of Scientific Renaissance (Sanderson, 2012).

The Zewail City of Science and Technology project had been lying dormant ever since its mentor, Nobel Prize laureate Ahmed Zewail, presented the concept to President Mubarak in 1999. The project was later revived, in recognition of the fact that Egypt would only be able to develop a knowledge economy if it could foster a technopreneurship culture led by projects such as Zewail's. In April 2014, President Al-Sissi decided to allot 200 acres to the Zewail City of Science and Technology for its permanent campus in the Sixth of October city, situated about 32 km from central Cairo. Once completed, Zewail City for Science and Technology[9] will have five constituents: a university, research institutes, a technology park, an academy and a centre for strategic studies.

The Academy of Scientific Research and Technology (ASRT) was founded in 1972. This non-profit organization is affiliated with the Ministry of Higher Education and Scientific Research (MoHSR), born of the merger with the Ministry of Higher Education in September 2015. It is not an academy of sciences in the conventional sense of the word as, until 2007, it controlled the budget for R&D in universities and research centres. Today, it acts as a think-tank and policy advisor to the ministry and co-ordinates the country's research programmes.

In early 2015, the Ministry of Scientific Research (MoSR) began putting the final touches to Egypt's *Strategy for Science, Technology and Innovation*. In February 2015, UNESCO provided the ministry with technical assistance in organizing a Policy Dialogue on STI in the presence of international experts. A report commissioned subsequently by UNESCO proposed a series of recommendations for nurturing scientific research in Egypt (Tindemans, 2015). These include:

- A platform should be established at cabinet level with stakeholders from the economy and society to devise a vision and strategy for enhancing the role played by STI in socio-economic development;
- In order to improve the monitoring and co-ordination of policy implementation and facilitate evaluation, MoSR should play a decisive role in the budgetary cycle for the institutes under its supervision and should publish each year a comprehensive overview of public and private sector expenditure on R&D; the ministry should also head a high-level permanent committee of civil servants from ministries entrusted with responsibility for collecting and validating basic information on the national innovation system;
- The Ministry of Scientific Research should develop close ties to the Ministry of Industry of Trade;
- Parliament should adopt a legal framework for scientific research comprised of both generic and more specialized laws;
- Patent law should be less rigid to favour innovation;
- Government departments need to be much more knowledgeable about the needs and aspirations of the private sector; they need to engage in much closer collaboration with the Industrial Modernization Centre, the Federation of Egyptian Industries;
- ASRT and MoSR should set up a framework to promote industrial innovation and co-operation by firms with universities and government research institutes;
- A national innovation funding agency should be set up to support private sector research and public–private co-operation, with the provision of competitive funding being its core task;
- The Egyptian Science, Technology and Innovation Observatory should consider it a priority to obtain information on both public and private sector investment in R&D; current data on GERD and researchers need to be subjected to critical analysis to ensure their reliability; the establishment of a panel of independent international experts could help with this critical analysis; and
- The Ministry of Scientific Research should develop close ties to the Ministry of Higher Education. The shortfall in scientific research is also reflected in the non-contextualization of learning materials in tertiary curricula.

IRAQ

Scientific research inscribed in the Constitution

Once a regional powerhouse of R&D, Iraq has lost its institutional and human capital to successive wars since 1980 and the subsequent exodus of its scientists. Since 2005, the Iraqi government has been seeking to restore the country's proud heritage. Iraq's Constitution of 2005 stipulates that 'the State shall encourage scientific research for peaceful purposes that serve humanity and shall support excellence, creativity, innovation and different aspects of ingenuity' (Article 34).

In 2005, UNESCO began helping Iraq to develop a Master *Plan for Science, Technology and Innovation* that would ultimately cover the period 2011–2015, in order to revive the economy in the aftermath of the US-led invasion in 2003 and to address pressing social needs such as poverty and environmental degradation. Following an analysis of the strengths and weaknesses of different sectors, UNESCO accompanied Iraq in preparing a *Framework and Agenda for Action* (2013) to complement the country's *National Development Plan* for the years 2013–2017 and to set the stage for a more comprehensive STI policy.

In 2010, the Universities of Baghdad, Basra and Salahaddin province joined the Avicenna Virtual Campus for Science and Technology. This gives them access to the teaching materials produced by other members of the UNESCO network,[10] which the Iraqi universities can then enrich with their own content. Further expansion of the Avicenna network within Iraq has been perturbed by the occupation of swaths of Iraqi territory by the Da'esh terrorist group.

9. see: www.zewailcity.edu.eg

10. Avicanna also involves universities from Algeria, Cyprus, Egypt, France, Italy, Jordan, Lebanon, Malta, Morocco, Palestine, Spain, Syria, Tunisia, Turkey and the UK.

On 20 June 2014, Iraq launched its first satellite for environmental monitoring. TigrisSat was launched from a base in the Russian Federation. The satellite is being used to monitor sand and dust storms in Iraq, as well as potential precipitation, vegetative land cover and surface evaporation.

JORDAN

Plans for an observatory of STI

Jordan's Higher Council for Science and Technology (est. 1987) is an independent public body that acts as a national umbrella organization for scientific research. It is the Higher Council for Science and Technology which drew up the first national policy for science and technology in 1995. In 2013, it completed the national *Science, Technology and Innovation Policy and Strategy* (2013–2017), which has seven broad objectives. These are to:

- incite the government and the scientific community to adopt the R&D priorities for developing a knowledge economy identified by the council and the Scientific Research Support Fund in 2010 in *Defining Scientific Research Priorities in Jordan for the Years 2011–2020*;
- generalize a science culture in the education system;
- harness R&D to development;
- build knowledge networks in science, technology and research;
- adopt innovation as a key stimulus for investment opportunities;
- translate the results of R&D into commercial ventures; and
- contribute to excellence in training and skills acquisition.

The Higher Council for Science and Technology has identified five domains in which projects are to be implemented to operationalize the policy: the institutional framework; policies and legislation; STI infrastructure; human resources; and the STI environment. An analysis of the national innovation system revealed that research was making an insufficient contribution to economic growth and to solving chronic problems, such as those related to water, energy and food. For the 2013–2017 period, some 24 projects have been proposed at a projected cost of around US$ 14 million that is still to be allocated by the government. These include a review of the national STI policy, institutionalizing innovation, developing incentive schemes for researchers and innovators, founding technology incubators and setting up a research database. A unit is to be created within the Higher Council for Science and Technology specifically for expatriate Jordanian scientists. The council is responsible for implementing, following up and evaluating all 24 projects, along with relevant ministries.

For over six years, the Higher Council for Science and Technology has been involved in a project that is setting up an Observatory of Science, Technology and Innovation, in collaboration with the United Nations' Economic and Social Commission for Western Asia (ESCWA). The observatory will maintain the country's first comprehensive database of domestic R&D and is to be hosted by the council.

In 2013, the Higher Council for Science and Technology published the *National Innovation Strategy*, 2013–2017, which had been prepared[11] in collaboration with the Ministry of Planning and International Co-operation with the support of the World Bank. Targeted fields include energy, environment, health, ICTs, nanotechnology, education, engineering services, banking and clean technologies.

Revival of two research funds

Jordan's Scientific Research Support Fund[12] was revived in 2010 after being instituted in 2006. Administered by the Ministry of Higher Education and Scientific Research, it finances investment in human resources and infrastructure through competitive research grants related to ecological water management and technological applications. The fund backs entrepreneurial ventures and helps Jordanian companies to solve technical problems; it also encourages private bodies to allocate resources for R&D and provides university students with scholarships based on merit. So far, the fund has provided 13 million Jordanian dinars (*circa* US$ 18.3 million) to finance R&D projects in Jordan, 70% of which has been used to fund projects in energy, water and health care.

The revamped Scientific Research Support Fund is also intended to streamline the activities supported by the Fund for Scientific Research and Vocational Training (est. 1997). This fund was launched partly to ensure that all public share-holding Jordanian companies either spent 1% of their net profits on research or vocational training within their own structure or paid an equivalent amount into the fund for redistribution for the same purpose. The problem was that the definition of what constituted research and vocational training was too broad. As a result, new regulations were adopted in 2010 to clarify the terms and provide for the collection of the 1% to be spent on R&D.

Jordan is home to the King Abdullah II Design and Development Bureau (KADDB), an independent government entity within the Jordanian Armed Forces that develops defence products and security solutions for the region. KADDB works with Jordanian universities to help students tailor their research projects to KADDB's needs.

11. Despite the similarity in name, this document differs from the *Science, Technology and Innovation Policy and Strategy* (2013–2017).

12. See: www.srf.gov.jo

Box 17.3: SESAME project soon to light up the region

Jordan is home to the region's first major interdisciplinary science centre, the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME), which houses the highest energy accelerator in the Middle East.

Synchrotrons work by accelerating electrons around a circular tube at high speed, during which time excess energy is given off in the form of light. By focusing this intense light, the tiniest structures can be mapped in great detail. The light source acts like a super X-ray machine and can be used by researchers to study everything from viruses and new drugs to novel materials and archaeological artefacts.

Synchrotrons have become an indispensable tool for modern science. There are some 50 such storage-ring-based synchrotron light sources in use around the world. The majority are found in high-income countries but Brazil (see Box 8.2) and China also have them.

By early 2017, construction of the storage ring will have been completed and the SESAME laboratory and its two beamlines will be fully operational, making it the first synchrotron light source in the region. Already, scientists are visiting SESAME for their work, thanks to the Fourier Transform Infrared microscope that has been in operation there since August 2014.

Construction of the centre began in 2003. SESAME has been established under the aegis of UNESCO as a co-operative intergovernmental venture by the scientists and governments of the region in which it is located. Its governance is assured by the SESAME Council.

The SESAME members are Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey. There are also observers: Brazil, China, the European Union, France, Germany, Greece, Italy, Japan, Kuwait, Portugal, the Russian Federation, Spain, Sweden, Switzerland, the UK and USA.

Alongside its scientific aims, SESAME promotes solidarity and peace in the region through scientific co-operation.

Source: Susan Schneegans, UNESCO
See: www.sesame.org.jo/sesame

Jordan has hosted the ESCWA Technology Centre since its inception in 2011. The centre's mission is 'to assist member countries and their public and private organizations to acquire the necessary tools and capabilities to accelerate socio-economic development.'

Jordan also hosts the the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME), which should be fully operational by 2017 (Box 17.3).

KUWAIT

A difficult transition

The contribution of most non-oil economic sectors in Kuwait declined after the Iraqi invasion in 1990, especially after hundreds of companies and foreign institutions, including banking and investment brokers, moved their operations elsewhere in the region. The economic slowdown was mainly due to the flight of capital and the cancellation of important development projects like the petrochemical project with the Dow Chemical Company, which filed a lawsuit against Kuwait demanding compensation of US$ 2.1 billion. In May 2012, Dow Chemical won the case, thus increasing Kuwait's financial losses (Al-Soomi, 2012).

In the past few years, there have been some missed opportunities to implement development projects of significant economic value; in parallel, Kuwait's dependence on oil revenue has grown. Kuwait was a regional leader in science and technology and higher education in the 1980s but has been losing ground ever since. The World Economic Forum's 2014 *Global Competitiveness Report* reveals a significant deterioration in many STI-related indicators.

Besides the Ministry of Education and the Ministry of Higher Education, the three major players in science in Kuwait are the Kuwait Foundation for the Advancement of Sciences, Kuwait Institute of Scientific Research and Kuwait University. The Kuwait Foundation for the Advancement of Sciences developed a new plan in 2010–2011 to mobilize financial and human resources, in order to reinvigorate both the government and private sectors, with a concomitant desire to improve public understanding of science.

The Kuwait Institute of Scientific Research (est. 1967) carries out applied research in three broad fields: oil, water, energy and construction; environment and life sciences; and techno-economics. It also advises the government on research policy. In recent years, the institute has emphasized scientific excellence, a client focus, achieving international technological leadership, the commercialization of research results and the establishment of new centres. The current eighth strategic plan covering 2015–2020 focuses on technology roadmapping to develop system solutions for selected technologies in oil, energy, water and life sciences.

The Kuwait University Research Sector supports faculty initiatives in basic and applied research and in humanities. It offers research grants within a number of funding schemes and finances a joint research programme in the area of natural resources development with the Massachusetts Institute of Technology in the USA. For its part, the Kuwait University Research Park has a more commercial focus. It aims to lay the foundations for innovation and spin-off technologies with scope for industry–research linkages and potential for patenting and marketing. Faculty researchers have made headway; they announced the acquisition of six US patents during the 2010/2011 academic year, two new patent awardees the following year and four in 2012/2013.

LEBANON

Three instituitions dominate research

Despite the existence of over 50 private universities and one public one, most research[13] in Lebanon is carried out by just three institutions: the Lebanese University, Saint-Joseph University and the American University of Beirut. On occasion, these three institutions collaborate with one of the four research centres managed by the National Council for Scientific Research (CNRS, est. 1962) and/or the Lebanese Agricultural Research Institute.

Lebanon counts several NGOs active in science, including the Arab Academy of Sciences (est. 2002) and the Lebanese Association for the Advancement of Science (est. 1968). The Lebanese Academy of Sciences was created by government decree in 2007.

As there is no ministry in charge of national policy-making in science and technology, the CNRS is considered as the main umbrella organization for science and the government advisor in this field, under the authority of the prime minister. The CNRS fulfils an advisory function, drawing up the general outline of Lebanon's national science policy. It also initiates, encourages and co-ordinates research projects. It is also responsible for managing the Centre for Geophysics, the Centre for Marine Sciences, the Centre for Remote Sensing and the Lebanese Atomic Energy Commission.

In 2006, the CNRS finished drafting the national *Science, Technology and Innovation Policy* with support from UNESCO and ESCWA.[14] The policy introduced new funding mechanisms for research and encouraged researchers from various institutions to work together under the umbrella of an associated research unit on major multidisciplinary themes. It also introduced new programmes to boost innovation and capacity-building, joint PhD programmes and established the basis for Lebanese participation in key Euro-Mediterranean projects.

The policy also identified a series of national priority research programmes inspired by the work of specialized task forces:

- Information technology (IT) deployment in the enterprise sector;
- Web and Arabized software technologies;
- Mathematical modelling, including financial/economic applications;
- Renewable energy sources: hydro-electric, solar, wind;
- Material/Basic sciences for innovative applications;
- Sustainable management of coastal areas;
- Integrated water management;
- Technologies for new agricultural opportunities, including the medicinal, agricultural and industrial use of local plant biodiversity;
- Nutritional food quality;
- Research in subfields of molecular and cellular biology;
- Research in clinical sciences;
- Forging links between practitioners of medical and health sciences, social sciences and paramedical professions.

An observatory of STI

The CNRS has incorporated these R&D priorities into its own research grant programme (Figure 7.13). Moreover, as follow-up to the *Science, Technology and Innovation Policy,* it embarked on establishing the Lebanese Observatory for Research, Development and Innovation (LORDI) in 2014 with support from ESCWA, in order to monitor key indicators of R&D input and output. Lebanon participates in a platform linking Mediterranean observatories of STI. This co-operative platform was set up by the Mediterranean Science, Policy, Research and Innovation Gateway (Med-Spring project) within the EU's Seventh Framework Programme for Research and Innovation (2007–2013).

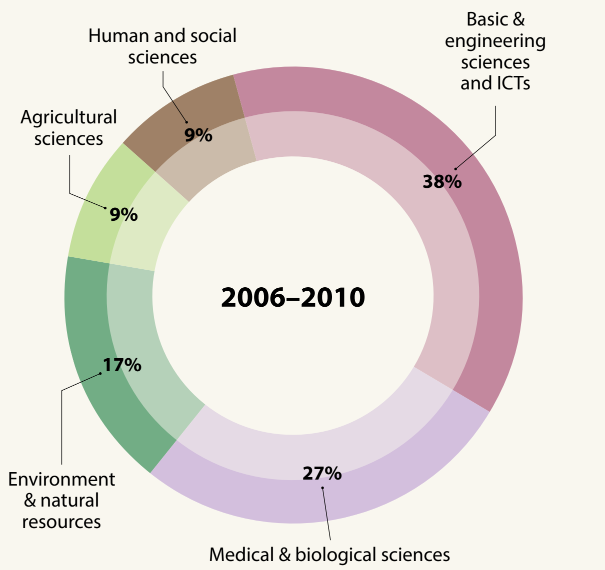
Lebanon's first comprehensive energy strategy

In November 2011, the Lebanese Council of Ministers officially adopted the *National Energy Efficiency Action Plan* for the years 2011–2015. This plan had been developed by the Lebanese Centre for Energy Conservation, the technical arm of the Ministry of Energy and Water in the areas of energy efficiency, renewable energy and 'green' buildings. This is the first comprehensive strategy in energy efficiency and renewable energy for a country

13. http://portal.unesco.org/education/en/files/55535/11998897175Lebanon.pdf/Lebanon.pdf

14. UNESCO has an office in Beirut and ESCWA is hosted by Lebanon.

Figure 17.13: **Distribution of research grants by the Lebanese National Council for Scientific Research, 2006–2010 (%)**



Source: presentation by the Lebanese National Council for Scientific Research (CNRS) to a meeting of the Mediterranean network of observatories of STI, December 2013

that depends on imports for 95% of its energy requirements. The plan is a Lebanese version of the *Arab Energy Efficiency Guidelines* developed by the League of Arab States and comprises 14 national initiatives designed to help Lebanon reach its target of 12% renewable energy by 2020.

LIBYA

The legacy of extreme state control still visible

During the four decades preceding the 2011 uprising, the Libyan economy had drifted towards near-complete state control. Private property ownership and private sector activity in sectors such as retail and wholesale trading were severely curtailed by law, while uncertainty over tax and regulatory regimes prevented the development of economic activity beyond the oil sector; today, this sector is still officially controlled by the National Oil Corporation, which mimics a ministry, in addition to being a regulatory agency and state-owned company. Mining and quarrying represented 66% of GDP in 2012 and 94% of government revenue a year later (AfDB, 2014).

This economic and intellectual suffocation led to large-scale brain drain, making Libya dependent on a sizeable immigrant population to drive highly skilled sectors, among others. There are currently an estimated 2 million foreign workers in Libya, most of whom are illegal (ETF, 2014).

Despite immigrant labour, the Libyan economy was also characterized by a relatively low economic participation rate of around 43% of the adult population between 2008 and 2013 (Table 17.1). Moreover, in its *Rapid Assessment of the Libyan Labour Market* in 2012, the World Bank estimated that 83% of employees were working in government or government-owned enterprises.

The extreme degree of state control was also reflected in Libya's STI environment. Between 2009 and 2013, every single researcher in Libya was employed by the government sector, according to the Libyan Authority for Research, Science and Technology, although it does not survey the business enterprise sector. According to the same source, the number of FTE researchers rose over this period from 764 to 1 140, representing a leap from 128 to 172 FTE researchers per million inhabitants, even if this remains a low ratio for a high-income country like Libya. Despite the turmoil, Libyan researchers managed to increase their annual output from 125 to 181 papers between 2009 and 2014, according to the Web of Science. There are no available data but the Libyan oil industry is known to conduct research on its own behalf.

Political fragmentation delaying recovery

Libya's first post-revolution national elections in July 2012 formally transferred power from the National Transitional Council to the General National Congress in August 2012. Soon afterwards, the country descended into armed conflict. The Council of Deputies (parliament) was formed after the June 2014 elections and is recognized as the legitimate government of Libya by the international community. Currently, it meets in virtual exile in Tobruk, near the Egyptian border. Meanwhile, the country's constitutional capital, Tripoli, is held by supporters of a New General National Congress composed of Islamists who fared poorly in the low-turnout elections. In Benghazi and elsewhere, the climate of insecurity has delayed the start of the school and academic years.

Initially, disruptions to oil production caused a 60% contraction in GDP in 2011 but the economy recovered remarkably quickly, rebounding by 104% in 2012. The deteriorating security situation since, coupled with protests at oil terminal cities since the second half of 2013, have augmented macro-economic instability, causing GDP to contract by 12% in 2013 and the fiscal balance to plummet from a surplus of 13.8% in 2012 to a deficit of 9.3% in 2013 (AfDB, 2014). Private sector activity remains subdued, given the current political uncertainty, exacerbating weak regulatory and institutional conditions and restrictive regulations that limit job creation. Libya's development potential has been further weakened by new laws passed in 2013 limiting foreign ownership of companies to 49% (down from 65% under earlier legislation).

Returning Libyans could help to rebuild higher education

Once security returns, Libya can hope to tap into its large oil wealth to begin building its national innovation system. Priority areas should include strengthening the higher education system and wooing talented Libyans living abroad.

According to the Libyan Authority for Research, Science and Technology, there were an estimated 340 000 tertiary students in 2013/2014 (54% female), down from 375 000 in 2003. This compares with an 18–25-year cohort in excess of 600 000, according to the UNESCO Institute for Statistics. A development plan for 2008–2012 with a budget of US$ 2 billion had envisaged the creation of 13 new universities, on top of the existing 12. While much of the physical infrastructure has since been built, the upheavals since 2011 have prevented these new universities from opening their doors.

Returning Libyan brains could potentially play a major role in rebuilding the Libyan higher education system, with the right incentives. Currently, an estimated 17 500 Libyans are pursuing postgraduate studies abroad, compared to 22 000 within the country. According to the Libyan higher education authorities, there were approximately 3 000 Libyan students enrolled in postgraduate studies at British universities alone and almost 1 500 in North America in 2009. Anecdotal evidence suggests that the security situation has since triggered a fresh exodus of talent: the number of Libyan students enrolled in Malaysian universities, for instance, grew by 87% between 2007 and 2012 from 621 to 1 163 (see Figure 26.9).

A national strategy for STI

In October 2009, the Libyan Ministry of Higher Education and Scientific Research launched the first programme to provide Libyan researchers with direct funding. The aim of this ongoing programme is to disseminate a research culture in Libyan society, including both the government and business enterprise sectors. The programme disbursed more than US$ 46 million between 2009 and 2014.

In December 2012, the ministry established a national committee to lay the foundations of a national innovation system, under the stewardship of the Libyan Authority for Research, Science and Technology and in collaboration with all economic sectors. The committee prepared a draft National Strategy for Science, Technology and Innovation and instigated several prizes: students from the country's main universities competed in the first round of the entrepreneurship prize – supported by the British Council – in the 2012/2013 academic year and in the first round of the innovation prize in the 2013/2014 academic year.

The *National Strategy for Science, Technology and Innovation* was approved by the Libyan National Planning Council in June 2014. The strategy fixes some long-term targets, such as that of raising GERD to 2.5% of GDP by 2040 (Table 17.6). It also foresees the establishment of centres of excellence, smart cities, business incubators, special economic zones and technology parks, as well as the creation of an STI information database. Science and technology are to be harnessed to ensure sustainable development and security.

Table 17.6: **Libyan targets for STI to 2040**

	2014	2020	2025	2030	2040
FTE researchers per million inhabitants	172^{-1}	5 000	6 000	7 500	10 000
GERD/GDP ratio (%)	0.86	1.0	1.5	2.0	2.5
Number of patents	0	20	50	100	200
Number of published journals	25	100	200	500	1 000
Number of research proposals	188	350	650	1 250	2 250
Number of SMEs specializing in STI	0	10	50	100	200
Share of private sector expenditure on R&D in GERD (%)	0	10	15	20	30
Private sector income from R&D (% of GDP)	0	1	5	10	30
Share of technological products in exports (%)	0	5	10	15	40
Number of PhD students	6 000	8 000	10 000	8 000	8 000
Innovation score (Global Innovation Index)	135	90	70	50	30
Global Competitiveness Index (World Economic Forum)	3.5	3.7	3.9	4.0	4.5

-*n* = *n* years before reference year

Source: Libyan National Planning Council (2014) *National strategy for Science, Technology and Innovation*

R&D priorities have yet to be identified but, according to the strategy, should focus on problem-solving research, Libya's contribution to international knowledge production and on diversifying Libya's technological capabilities through investment in such areas as solar energy and organic agriculture.

MAURITANIA

Towards a national strategy for STI

The main finding of the *Science Technology and Innovation Policy Review of Mauritania*[15] undertaken by the United Nations Conference on Trade and Development and UNESCO in 2010 was that current capabilities were inadequate to address the challenges faced by the country. Most public and private enterprises lack the capacity to innovate that would make them internationally competitive. The skills base needs developing, particularly in scientific and technical disciplines, as well as in entrepreneurship and management. Also needed are more rapid technology diffusion and a greater absorptive capacity of technology. Some of the main shortcomings identified were:

- Limited and uncertain public financing for public R&D and lack of private sector investment in R&D or training;
- No active promotion of domestic quality standards as a means of improving the quality of domestic production and encouraging private investment in training and improved technologies;
- An excessively theoretical (as opposed to applied) focus of research at the University of Nouakchott and a lack of co-ordination between the university, public research institutes and ministries for training and R&D;
- A need to reduce bureaucratic obstacles to starting and operating a business;
- A weak entrepreneurial base sustained by the lack of business development services and by a culture of trading rather than investment in production;
- Lack of access by domestic enterprises to information on available technologies and the transfer and absorption of foreign technologies; and
- A lack of policies to leverage the significant reserve represented by the diaspora for domestic benefit.

With the technical assistance of UNESCO, Mauritania is currently drafting the national STI strategy recommended by the review. The focus is on developing skills and physical infrastructure, as well as on improving the co-ordination of private sector development policies, education reform and trade and foreign investment policies. Reforms will also need to build strong productive capacities in agriculture and fisheries, the mining industry and services sector, in order to take advantage of any improvement in macro-economic conditions.

New institutions and a plan for higher education

Mauritania's first tertiary institution, the National School of Administration, dates back to 1966; it was followed by the National School of Higher Studies (École nationale supérieure) in 1974 and the University of Nouakchott in 1981. Between 2008 and 2014, the government licensed three private tertiary colleges and founded the Institute of Higher Technological Studies (Institut supérieur des études technologiques, 2009) in Rosso and the University of Science, Technology and Medicine (2012). The new university has about 3 500 students and 227 teaching staff, including researchers. It is comprised of a Faculty of Science and Technology, a Faculty of Medicine and a professional training institute.

These developments reflect the government's will to improve access to higher education for the growing population. In accordance with the ten-year *Strategy for Science, Technology and Innovation* adopted by the African Union in 2014 (see Chapter 19), the government intends to use higher education as a lever for economic growth.

In April 2015, the Ministry of Higher Education and Scientific Research adopted an ambitious *Three-Year Plan for Higher Education* covering 2014–2017. This plan has four main objectives:

- Strengthen institutional management and governance of tertiary institutions;
- Improve the relevance of the curricula, the quality of training and the employability of graduates;
- Broaden access to tertiary study programmes; and
- Promote scientific research on major national development issues.

For the first time, the current administration has managed to collect relatively comprehensive data on higher education and scientific research data across the country. These data should enable the Ministry of Higher Education and Scientific Research and line ministries to identify the main obstacles to research.

15. See: http://unctad.org/en/Docs/dtlstict20096_en.pdf

MOROCCO

Added value a must to maintain competitiveness

Morocco has managed to navigate the fallout from the global financial crisis relatively well, with average growth of over 4% between 2008 and 2013. As Europe is the main destination for Moroccan exports, these have nevertheless been affected by the slowdown in the European economy since 2008. The economy is diversifying but remains focused on low value-added products; the latter still represent about 70% of manufactured goods and 80% of exports. Unemployment remains high, at over 9% (Table 17.1), and about 41% of the labour force lacks any qualification. There are also signs of waning competitiveness in some areas: in recent years, Morocco has conceded market shares for clothing and shoes in the face of tough international competition from Asia, in particular, but managed to expand its market share for fertilizers, passenger vehicles and equipment for the distribution of electricity (Agénor and El-Aynaoaui, 2015).

Morocco's S&T system is essentially centred around the Ministry of Higher Education and Scientific Research (MoHESR) and the Inter-Ministerial Permanent Committee on Scientific Research and Technological Development (est. 2002), together with the Hassan II Academy of Science and Technology (est. 2006). The National Centre for Scientific and Technical Research (CNRST) is another key player; it runs the National Support Programme for Sectorial Research, for instance, which issues calls for research proposals to public institutions.

Less than a year after its inception, the Higher Council for Education, Training and Scientific Research[16] presented a report to the king on 20 May 2015 offering a *Vision for Education in Morocco 2015–2030*. The report advocates making education egalitarian and, thus, accessible to the greatest[17] number. Since improving the quality of education goes hand in hand with promoting R&D, the report recommends developing an integrated national innovation system which would be financed by gradually increasing the share of GDP devoted to R&D 'to 1% in the short term, 1.5% by 2025 and 2% by 2030'.

The *Moroccan Innovation Strategy* was launched at the country's first National Innovation Summit in June 2009 by the Ministry of Industry, Commerce, Investment and the Digital Economy. It has three main thrusts: to develop domestic demand for innovation; foster public–private linkages; and introduce innovative funding mechanisms. Today, the latter include Intilak for innovative start-ups and Tatwir for industrial enterprises or consortia. The ministry is supporting research in advanced technologies and the development of innovative cities in Fez, Rabat and Marrakech.

The *Moroccan Innovation Strategy* fixed the target of producing 1 000 Moroccan patents and creating 200 innovative start-ups by 2014. In parallel, the Ministry of Industry, Commerce and New Technologies (as it had since become) created a Moroccan Club of Innovation in 2011, in partnership with the Moroccan Office of Industrial and Commercial Property. The idea is to create a network of players in innovation, including researchers, entrepreneurs, students and academics, to help them develop innovative projects.

Morocco's third technopark is scheduled to welcome its first start-ups and SMEs in September 2015. Like its two predecessors in Casablanca and Rabat, the new technopark in Tangers will be hosting companies specializing in ICTs, green technologies and cultural industries. Through a public–private partnership, offices in an existing building have been converted for an estimated cost of 20 million dirhams (MAD, *circa* US$ 2 million). They should be able to accommodate up to 100 enterprises, which will be sharing the premises with some of the project's key partners, such as the Moroccan Entrepreneurial Network and the Association of Women CEOs of Morocco (Faissal, 2015).

The National Fund for Scientific Research and Technological Development was adopted by law in 2001. At the time, domestic enterprises funded just 22% of GERD. The government encouraged companies to contribute to the fund to support research in their sector. Moroccan telecom operators were persuaded to cede 0.25% of their turnover; today, they finance about 80% of all public research projects in telecommunications supported through this fund. The financial contribution of the business enterprise sector to GERD has meanwhile risen to 30% (2010).

The government is also encouraging citizen engagement in innovation on the part of public institutions. For instance, the Moroccan Phosphate Office (Office chérifien des phosphates) is investing in a project to develop a smart city, King Mohammed VI Green City, around Mohammed VI University located between Casablanca and Marrakesh, at a cost of MAD 4.7 billion (*circa* US$ 479 million).

University–business partnerships remain very limited in Morocco. Nevertheless, a number of competitive funds fostering this type of collaboration have been renewed in recent years. These include the following:

16. The council was founded in accordance with the provisions of Article 168 of the Moroccan Constitution of 2011.

17. The *National Strategy for the Development of Scientific Research to 2025* (2009) recommended raising the secondary enrolment rate from 44% to at least 80% and the tertiary enrolment rate for 19–23 year-olds from 12% to over 50% by 2025.

- The third InnovAct programme was launched by the Moroccan Research Association in 2011, according to Erawatch. Whereas the programme's two predecessors (launched in 1998 and 2005) had targeted SMEs, the new programme has extended the beneficiary groups to include consortia of enterprises. SMEs are expected to pay 50–60% and consortia 80% of the project costs. The scheme encourages university–industry collaboration; companies receive logistical support and the financial means to recruit university graduates to work on their research project. The programme aims to support up to 30 enterprises each year operating mainly in the following industries: metallurgical, mechanical, electronic and electrical; chemical and parachemical; agro-food; textiles; technologies for water and environment; aeronautics; biotechnology; nanotechnology; off-shoring; and automotive;
- The Hassan II Academy of Sciences and Technology funded 15 research projects in 2008 and 2009. Calls for research proposals encourage private–public collaboration and take into consideration the project's potential socio-economic impact or spillovers;
- MoHESR places a number of poles of competence under contract for four years to bring together public and private research establishments together on a joint project through its accredited laboratories. There were 18 poles of competence up until 2010 but these have since been whittled down to 11 after several did not meet the ministry's new criteria for funding. The networks include one on medicinal and aromatic plants, another on higher energy physics, a third on condensed matter and systems modelling and a fourth on neurogenetics;
- The Moroccan Spin-off and Incubation Network *(Réseau Maroc incubation et essaimage)*[18] supports business incubation, in general, and technology transfer through university spin-offs, in particular. It provides start-ups with pre-seed capital to help them develop a solid business plan. The network is co-ordinated by the CNRST and currently groups 14 incubators at some of the top Moroccan universities.

18. See: www.rmie.ma

One in five graduates moves abroad

Each year, 18% of Moroccan graduates head mainly for Europe and North America; this trend has led to calls for foreign universities to be established in Morocco and for the development of prestigious campuses.

The Hassan II Academy of Science and Technology has international scientific outreach. In addition to recommending research priorities and evaluating research programmes, it helps Moroccan scientists to network with their national and international peers. The academy has identified a number of sectors where Morocco has a comparative advantage and skilled human capital, including mining, fisheries, food chemistry and new technologies. It has also identified a number of strategic sectors, such as energy, with an emphasis on renewable energies such as photovoltaic, thermal solar energy, wind and biomass; as well as the water, nutrition and health sectors, the environment and geosciences (HAST, 2012).

A growing investment in renewable energy

Morocco is expanding its investment in renewable energies (Box 17.4). A total of MAD 19 million (*circa* US$ 2 million) has been earmarked for six R&D projects in the field of solar thermal energy, under agreements signed by the Institute for Research in Solar and New Energy (IRESEN) with scientific and industrial partners. Moreover, IRESEN is currently financing research in the field of renewable energy that is being conducted by more than 200 engineers and PhD students and some 47 university teachers-cum-researchers.

Box 17.4: Morocco plans to lead Africa in renewables by 2020

Morocco has decided to compensate for its lack of hydrocarbons by becoming the leader in Africa for renewable energy by 2020. In 2014, it inaugurated the continent's biggest wind farm at Tarfaya in the southwest of the country.

The government's latest project is to create the world's biggest solar farm at Ouarzazate. The first phase, known as Noor I, should be completed by October 2015.

A consortium led by the Saudi Arabian company Acwa Power and its Spanish partner Sener won the call for tenders for the first phase and Acwa Power has just won the same for the second phase. It is estimated that it will cost the consortium nearly € 2 billion to build and run Noor II (200 MW) and Noor III (150 MW).

The project is also being funded by donors such as the German public bank Kreditanstalt für Wiederaufbau (€ 650 million) and the World Bank (€ 400 million).

Ultimately, the Ouarzazate solar farm will have a capacity of 560 MW but the government doesn't intend to stop there. It plans to produce 2 000 MW of solar power by 2020.

Source: Le Monde (2015)

OMAN

An incentive scheme to bolster research

According to the 2012 country report by the US Energy Information Administration, hydrocarbons accounted for about 86% of government revenue and half of GDP in 2013. Oman has an ambitious plan to reduce the oil sector's contribution to GDP to 9% by 2020. The aim is to diversify the economy, such as by developing the tourism sector, as part of the government's *Economic Vision 2020*. There is little latitude for expanding agricultural production but Oman hopes to exploit its long coastline's potential for the development of fisheries and gas-based industries to achieve the goals of *Economic Vision 2020* (Salacanin, 2015).

Oman's S&T system is centred around the Ministries of Education and Higher Education and Sultan Qaboos University. The Research Council is Oman's sole research funding body and thus spearheads R&D in the country. Established in 2005, it has an extensive mandate. The Research Council has identified the hurdles facing Oman, such as complex administrative processes, little funding, research of poor quality and the lack of relevance of R&D to socio-economic needs (Al-Hiddabi, 2014).

To address these difficulties, the Research Council developed a *National Research Plan for Oman* in 2010 which is linked to Oman's overall development plans. The plan outlines three stages: the first priority is to improve the status of research and boost productivity; at the second stage, the priority will be to build national research capacity in priority areas determined by the availability of appropriately qualified personnel and the establishment of the requisite infrastructure; at the last stage, the focus will be on strengthening the country's niche areas.

The Research Council has also developed an incentive scheme to foster research excellence. The programme rewards researchers through an open research grant scheme tied to their output. Besides stimulating productivity, the idea is to increase the number of active researchers, motivate them to mentor postgraduate students and encourage them to publish in international, refereed journals and to apply for patents.

In October 2014, Oman hosted the General Meeting of the World Academy of Sciences (TWAS). Two months later, the Research Council co-organized the second Arab–American Frontiers Symposium with the US National Academy of Sciences to facilitate research collaboration between outstanding young scientists, engineers and medical professionals from the USA and a number of Arab states.

PALESTINE

More research links needed with the market

Although Palestine does not have a national STI policy, a recent innovation survey by Khatib *et al.* (2012) of the two industrial sectors of stone quarrying and food and beverages yielded encouraging findings. The survey found that both sectors were innovative and having a positive impact on employment and exports. The survey recommended directing academic programmes towards local economic development to help establish the necessary co-operative links between the public and private sectors.

The Palestine Academy of Sciences and Technology (PALAST) acts as an advisory body for the government, parliament, universities and research institutes, as well as for private donors and international organizations. One of PALAST's special features is the presence of a powerful standing committee made up of a number of government ministers; the standing committee operates alongside a scientific council of elected members from PALAST (PALAST 2014).

An observatory of STI

In 2014, PALAST launched its Science, Technology and Innovation Observatory, which had been developed with the support of ESCWA. The observatory's main purpose is to collect data on STI on a regular basis and promote networking.

Hundreds of entrepreneurial web sites have been created by young Palestinians in the past few years to showcase new digital products that include games and software for specific professions. Although internet connection costs have fallen by almost 30% in recent years, the lack of connectivity to a 3G network in the West Bank and Gaza Strip hinders the use of mobile applications for education, health and entertainment.

QATAR

Incentives for entrepreneurship

Besides its oil and gas industry, Qatar relies on the petrochemical, steel and fertilizer industries to drive the economy. In 2010, Qatar showed the world's fastest growth rate for industrial production: 27.1% over the previous year. Qataris enjoy the world's highest GDP per capita (PPP$ 131 758) and one of the world's lowest unemployment rates: 0.5% (Table 17.1).

The *Qatar National Vision 2030* (2008) advocates finding an optimum balance between the current oil-based economy and a knowledge economy characterized by innovation and entrepreneurship, excellence in education and the efficient delivery of public services. To support this shift towards a knowledge economy, the government budget for education to 2019 has been raised by about 15%.

The government has also begun offering investors tax breaks and other incentives to support entrepreneurship and promote SMEs. Its efforts to diversify the economy appear to be paying off. Industries and services derived from hydrocarbons have been expanding, fuelling private-sector growth. Although the manufacturing sector is still in its infancy, there has been a boom in the construction sector, thanks largely to heavy investment in infrastructure; this in turn has boosted the finance and real estate sectors (Bq, 2014). Much of construction is occurring in the non-hydrocarbon sector: in transportation, health, education, tourism and sport – Qatar is hosting the World Football Cup in 2022. The government is also promoting Qatar as a tourist destination among its neighbours, in particular. Consequently, non-hydrocarbon sectors grew by 14.5% in 2013.

Qatar's new park is country's primary technology incubator

The *Qatar National Research Strategy* (2012) identified four priority areas: energy, environment, health sciences and ICTs. When the Qatar Foundation subsequently established the Qatar Science and Technology Park, it focused on these four areas. The park has become Qatar's primary incubator for technological development, the commercialization of research and support for entrepreneurship. Located within the Qatar Foundation's Education City, the park has access to the resources of a cluster of leading research universities with antennae in the park, including five US institutions: Virginia Commonwealth University School of the Arts, Weill Cornell Medical College, Texas A&M University at Qatar, Carnegie Mellon University and Georgetown University.

SAUDI ARABIA

Policies to reduce dependence on foreign labour

As part of its agenda for embracing the knowledge economy, the government has launched a multibillion dollar development scheme to build six greenfield cities and industrial zones. By 2020, these industrial cities are expected to generate US$ 150 billion in GDP and create 1.3 million jobs. This strategy has been endorsed by the record number of non-oil exports in 2013. However, Saudi Arabia remains overdependent on foreign labour: there are only 1.4 million Saudis employed in the private sector, compared with 8.2 million foreigners, according to the Ministry of Labour (Rasooldeen, 2014). The government is trying to recruit citizens through a drive dubbed 'Saudization'.

In parallel, the government is investing in professional training and education as a way of reducing the number of foreign workers in technical and vocational jobs. In November 2014, it signed an agreement with Finland to utilize Finnish excellence to strengthen its own education sector (Rasooldeen, 2014). By 2017, the Technical and Vocational Training Corporation of Saudi Arabia is to have constructed 50 technical colleges, 50 girls' higher technical institutes and 180 industrial secondary institutes. The plan is the first step in creating training placements for about 500 000 students, half of them girls. Boys and girls will be trained in vocational professions such as IT, medical equipment handling, plumbing, electricity, mechanics, beauty care and hairdressing.

Two universities among the top 500

Saudi Arabia has now entered the third phase of implementation of its first national S&T policy (2003). The policy called for the establishment of centres of excellence and for upgrading the skills and qualifications of human resources. The country is keen to co-operate with the outside world, invest more in information technologies and harness S&T to preserving its natural resources and protecting the environment.

The *Five-Year Development Plan* adopted in 2010 proposed allocating US$ 240 million in research grants each year, together with the creation of a number of research centres and technology incubators at different universities.

According to the 2014 Academic Ranking of World Universities, both King Abdulaziz University and King Saud University rank among the world's top 500. The former has succeeded in attracting over 150 highly cited[19] researchers from around the world as adjunct professors and the latter 15. Internationally recruited faculty are expected to undertake research in Saudi Arabia and collaborate with Saudi faculty members. This policy has allowed both universities to move up the field in international rankings, while boosting overall research output and building endogenous capacity in R&D.

King Abdulaziz City for Science and Technology (KACST) serves as both the national science agency and as a hub for national laboratories. It is involved in policy-making, data collection and funding of external research. It also acts as the national patent office. KACST's planning directorate is responsible for developing national databases with STI indicators. KACST conducts applied research in a wide range of areas, including petrochemicals, nanotechnologies, space and aeronautics, advanced materials, mathematics, health, agriculture and construction technologies. It also acts as a technology incubator by fostering ties between research universities and between the public and private sectors to

19. http://highlycited.com/archive_june.htm

Box 17.5: **Fellowships for budding inventors from the Gulf**

The Institute for Imagination and Ingenuity (i2 Institute) is the brainchild of Hayat Sindi, co-founder of Diagnostics for All, a non-profit company designated one of the world's ten most innovative biotech companies in 2012 by *FastCompany* magazine in the USA. Originally from Saudi Arabia, Dr Sindi was the first woman from the Gulf to obtain a PhD in biotechnology, while she was studying at Cambridge University (UK).

For Dr Sindi, 'the Middle East has to overcome huge barriers to entrepreneurship'. Chief among these are a lack of formal business skills among scientists and engineers; a culturally intrinsic fear of failure; a lack of potential investors willing to provide the necessary venture capital; and the fact that investors in the region do not focus on science-based ventures.

Dr Sindi founded the Institute for Imagination and Ingenuity in 2011 to accompany budding young inventors from the region at the incubation stage of their project. Her NGO helps them package their idea and attract venture capital through a three-stage fellowship programme, the only one of its kind in the Arab world.

The first call for applications took place in November 2012. Master's and PhD students were invited to apply for a grant in one of four areas: water, energy, health or environment. Some 50 candidates who already held a local and international patent for their idea were selected. They were then invited to pitch their idea to an international jury made up of scientists and business leaders in February 2013. Ultimately, just 12 fellows were singled out to share a grant of US$ 3–4 million; each was then assigned a regional and global mentor to help him or her develop a business plan.

The fellows were able to develop their business plan during the first stage of their eight-month fellowship, through the entrepreneur programme run jointly with Harvard Business School and the Massachusetts Institute of Technology (MIT) in the USA for a period of six weeks.

The second stage of their induction was the social science programme. Here, they met other fellows who had specialized in social innovation, such in as the provision of clean energy or water. All 12 fellows were asked to come up with a solution to a specific social problem. The aim of this exercise was to give them confidence in their ability to take on new challenges.

The third programme developed the i2 fellows' communication skills at MIT's Media Lab, teaching them how to sell their project to different audiences and how to speak in public.

In 2014, potential investors were invited to a conference hosted by King Abdullah Economic City in Riyadh (Saudi Arabia) to hear the fellows present their projects. The deadline for the second round of applications was end April 2014.

Source: www.i2institute.org; UNESCO (2013)

encourage innovation and the transfer and adaptation of technology with commercial potential.

One interesting initiative is the Institute for Imagination and Ingenuity founded by Makkah-born Dr Hayat Sindi in 2011; it is striving to develop an entrepreneurial culture in the Arab world through mentorship (Box 17.5).

Research to curb energy consumption

Saudi Arabia needs to engage in a serious deliberation about its domestic energy consumption, which is expected to increase by 250% by 2028. One-third of oil production was being used domestically in 2012 and demand is growing by about 7% per year, driven by increasing wealth, rapid population growth and low domestic energy prices. The OECD's International Energy Agency recorded about US$ 40 billion in domestic energy subsidies in 2011.The government is cognizant of the problem. In 2010, it upgraded the National Energy Efficiency Programme (launched in 2003) to a permanent faciliity, the Saudi Energy Efficiency Centre. In May 2015, the government announced a programme to develop solar energy which should allow the country to export gigawatts of electric power instead of fossil fuels.

The late King Abdullah was a keen proponent of education and research. In 2007, he called for the establishment of an independent centre to conduct objective research in the field of energy. This gave rise to the King Abdullah Petroleum Studies and Research Centre, which opened in Riyadh in 2013; a Board of Trustees ensures the centre's independence and oversees its endowment. In 2009, Saudi Arabia launched the King Abdullah University of Science and Technology.

SUDAN

Conflict and brain drain undermining development

Sudan has been plagued by armed conflict in the past decade: the conflict in Darfur, which lasted from 2003 until the signing of a ceasefire agreement with rebel groups in 2010; and a long-standing conflict in the south of the country, which resulted in the establishment of South Sudan as an independent state in 2011.

Sudan has had its own academy of sciences since 2006 but otherwise has struggled to consolidate its science system over the past decade. One impediment is the loss of young talent to brain drain: between 2002 and 2014, Sudan lost more than 3 000 junior and senior researchers to migration, according to the National Research Centre and Jalal (2014). Researchers are drawn to neighbouring countries such as Eritrea and Ethiopia by the better pay, which is more than double that offered to university staff in Sudan. More recently, Sudan has become a refuge for students from the Arab world, particularly since the turmoil of the Arab Spring. Sudan is also attracting a growing number of students from Africa.

In 2010, the privately run Future University in Khartoum was upgraded from a college to a university. Established in 1991, it was the first college in the region to introduce an IT programme, offering degrees in a wide range of fields, including computer science, artificial intelligence, bio-informatics, electronics engineering, geo-informatics and remote sensing, telecommunication and satellite engineering, biomedical engineering, laser and mechatronics engineering and architecture. The Future University is participating in NECTAR (Box 17.2).

A fresh policy impetus

In 2013, the Ministry of Science and Communication embarked on a revision of its *Science and Technology Policy* (2003) with the technical assistance of UNESCO. A number of consultation meetings were organized with high-level experts from around the world; these produced a series of recommendations, including those advocating:

- the re-establishment of a higher council for science and technology, to be headed by the First Deputy President of the Republic, which would co-ordinate and oversee relevant institutions and research centres attached to various ministries, with the Ministry of Science and Communications acting as rapporteur of the council.;
- the establishment of a fund to finance government research, with a focus on employing the proceeds of Awqaf and Zakat;[20] this should be combined with the adoption of legislation increasing financial allocations to scientific research, such as exemptions from some or all of customs duties on imported goods and equipment that support research; these measures should enable GERD to rise to 1% of GDP by 2021; and
- the establishment of an observatory of STI indicators, with the technical support of UNESCO.

Sudan has a fairly diverse institutional framework. The following research centres, among others, fall under the umbrella of the Ministry of Science and Communication:

- Agricultural Research Corporation;
- Animal Resources Research Corporation;
- National Research Centre;
- Industrial Research and Consultancy Centre;
- Sudan Atomic Energy Corporation;
- Sudanese Metrology Authority;
- Central Laboratories; and the
- Social and Economic Research Bureau.

Unfortunately, Sudan does not yet possess the human or financial resources necessary to promote science and technology effectively. Were it to encourage more private sector involvement and regional co-operation, restructure its essentially agriculture-based economic system and pool its resources, it would be in a position to develop its S&T capacity (Nour, 2012). The bilateral co-operation agreement signed by the Ministry of Science and Communication with the South African Department of Science and Technology in November 2014 is a step in the right direction. During the minister's visit to South Africa in March 2015, the Sudanese government identified space science and agriculture as priority areas for collaboration (see Table 20.6).

SYRIA

An exodus of scientific talent

Despite hosting prestigious international research institutes such as the International Centre for Agricultural Research in Dry Areas and the Arab Centre for the Study of Arid Zones and Dry Lands, Syria's S&T system was in a dire state even before the outbreak of civil war in 2011. Syrian parliamentarian Imad Ghalioun estimated in 2012 that, even before the uprising, the government had allocated just 0.1% (US$ 57 million) of GDP to R&D and, afterwards, as little as 0.04% of GDP (Al-Droubi, 2012). The civil war has led to an exodus of scientific talent. In 2015, the United Nations estimated that four million Syrians had sought refuge in neighbouring countries since 2011, mainly Jordan, Lebanon and Turkey.

TUNISIA

Greater academic freedom

During the difficult transition to democracy over the past four years, science and technology have often taken a back seat to more pressing problems. This has led to frustration in the scientific community at the speed of reform. The situation has improved for scientists in terms of academic freedom but other concerns persist.

20. Within Islam, Awqaf is a voluntary donation of money or assets which are held in trust for charitable purposes. Zakat is an obligatory religious tax paid by every Muslim that is considered one of the five pillars of Islam. There are established categories of beneficiary of this tax, which is used to maintain a socio-economic equilibrium by helping the poor.

The first reform was introduced within weeks of the revolution. During her brief stint as Secretary of State for Higher Education from January to March 2011 in the caretaker government, Faouzia Charfi changed the procedure for filling top university posts. For the first time in Tunisia, elections were held in June 2011 for faculty directors and university presidents (Yahia, 2012). This is a step forward, even if corruption continues to plague the Tunisian university system, according to a study published in June 2014[21] by the Tunisian University Forum, an NGO formed after 14 January 2011.

That this NGO could even publish such a study without fear of retribution is a sign, in itself, of greater academic freedom in Tunisia since President Zine El-Abidine Ben Ali fled the country on 14 January 2011. According to Faouzia Charfi, under the former president, 'universities and researchers had little freedom to develop their own strategies or even to choose who they worked with'. Other scientists have said that regime bureaucrats thwarted their attempts to establish independent links with industry (Butler, 2011). Scientists were also discouraged from maintaining international ties. Organizers of scientific meetings, for instance, were obliged to submit the topics and research on the agenda to regime bureaucrats, in order to obtain prior authorization. Ten months after the revolution, a group of PhD holders and students formed the Tunisian Association of Doctors and PhD Students in Science to help Tunisian scientists network with one another other and with scientists abroad (Yahia, 2012).

Despite restrictions, 48% of scientific articles published by Tunisian researchers had foreign co-authors in 2009. This share had risen to 58% by 2014. In 2009, the government began negotiating an agreement for a joint research programme with the European Union (EU). The three-year programme was ultimately launched on 12 October 2011, with € 12 million in EU funding. The Tunisian Agency for the Promotion of Scientific Research was given responsibility for distributing the programme funds in accordance with the country's priority research areas: renewable energy, biotechnology, water, the environment, desertification, micro-electronics, nanotechnology, health and ICTs. The programme also sought to forge links between academic research and the Tunisian industrial sector. The German Society for International Cooperation, for instance, conducted a study of market needs to help simplify co-ordination between the academic and industrial sectors. At the launch of the programme, the Tunisian Minister for Industry and Technology, Abd El-Aziz Rasaa, announced plans to raise Tunisia's technological exports from 30% of the total in 2011 to 50% by 2016 (Boumedjout, 2011).

21. See: www.businessflood.com/forum-universitaire-tunisien-etude-sur-le-diagnostic-et-la-prevention-de-la-corruption-dans-le-milieu-universitaire-tunisien

The economy has proved relatively resilient over the past four years, thanks partly to its broad base, with well-developed agricultural, mining, petroleum and manufacturing sectors. This helped to cushion the drop in tourism, which accounted for 18% of GDP in 2009 but only 14% four years later. Tourism was beginning to recover when terrorist acts against a museum and hotel complex in March and June 2015 once more destabilized the industry. Tunisia's relative stability and reputed health clinics have also made it a beacon for medical tourism.

High-level support for science

Compared to most African and Arab states, the STI system in Tunisia is fairly advanced and enjoys strong government support. The Higher Council of Scientific Research and Technology is chaired by none other than the prime minister himself. The body responsible for formulating policy and implementation strategies, the Ministry of Higher Education, Scientific Research and Information and Communication Technologies, can count upon the expertise of both the National Consultative Council of Scientific Research and Technology and the National Evaluation Committee of Scientific Research Activities. The latter is an independent body in charge of evaluating both public scientific research and private sector research programmes benefiting from the public purse. The National Observatory of Science and Technology is another vital component of the Tunisian STI system. It was established in 2006, two years before being placed under the Ministry of Higher Education and Scientific Research.

A strategy to build bridges between universities and industry

The University Council is presided by the Minister of Higher Education, Scientific Research and Information and Communication Technologies. In January 2015, the University Council approved a broad reform of scientific research and higher education that is to be implemented over the period 2015–2025. The reform will focus on modernizing university curricula, in order to give graduates the skills employers need, and on giving universities greater administrative and financial autonomy. In 2012, the ministry had already taken a step in this direction by placing its relations with universities on a contractual basis[22] for the first time.

The reform will also strengthen university–industry ties and revise the university map to ensure greater equity between regions. Central to this strategy is the ongoing development of technoparks, as they foster research and job creation in the regions.

Tunisia is investing heavily in technoparks. Elgazala Technopark in the Tunis region was the first, both for Tunisia and the

22. The two parties concluded a framework contract which authorizes universities and institutions to devise their own teaching and research strategies for a period of four years within the framework of specific projects and programmes; these strategies are accompanied by implementation plans.

Maghreb. Established in 1997, it specializes in communication technologies and now hosts about 80 companies, including 13 multinationals (Microsoft, Ericsson, Alcatel Lucent, etc). Several other technoparks have been established since, including those in Sidi Thabet (2002, for biotechnology and pharmaceuticals), Borj Cedria (2005, for environment, renewable energy, biotechnology and materials science), Monastir (2006, for textiles) and Bizerte (2006, for the agro-industry). In 2012, the government announced the creation of a new technopark in Remada specializing in ICTs. Meanwhile, the Ecosolar Village of Zarzis–Jerba should soon be operational. It will create jobs in renewable energy production, seawater desalination and organic farming; this technopark also plans to position itself as a training platform for the entire African region. Tunisia intends to raise the share of renewables in the energy mix to 16% (1 000 MW) by 2016 and to 40% (4 700 MW) by 2030, within its *Solar Plan*[23] adopted in 2009.

The longer term goal is to develop an internationally competitive research system. In November 2013, the government signed an agreement with France Clusters, which groups French technoparks, for the provision of training and advice on the creation of new technoparks in Tunisia. Elgazala and Sidi Thabet Technoparks are both members of the International Association of Science Parks. Gafsa Technopark, which specializes in useful chemical substances, has been designed in partnership with the Korean International Cooperation Agency; it is being funded by the government, the park management companies and the tandem formed by the Chemical Group and the Compagnie des phosphates de Gafsa.

The adoption of a new Constitution by parliament in June 2014, followed by the smooth handover of power, first in the October parliamentary elections then by the incumbent president to his successor, Beji Caid Essebsi, in late 2014, suggest that the country is well on the way to political stability. Moreover, science has not been forgotten in the new Constitution. Article 33 expressly states that 'the state provides the means necessary to the development of technological and scientific research'.

23. See: www.senat.fr/rap/r13-108/r13-108.pdf

UNITED ARAB EMIRATES

A good business climate

The United Arab Emirates has been reducing its dependence on oil exports by developing other economic sectors, including the business, tourism, transportation and construction sectors and, more recently, space technologies. Abu Dhabi has become the world's seventh-biggest port. The global financial crisis of 2008–2009 affected Dubai's real estate market, in particular. Companies like Dubai World, which supervised a government investment portfolio in urban development, ran up substantial external debt.

With the slump in oil prices since mid-2014, current economic growth is being buoyed mainly by the sustained recovery of Dubai's construction and real estate sectors, together with significant investments in transportation, trade and tourism. Dubai has launched a megaproject for the construction of the world's biggest shopping centre and no fewer than 100 hotels. It is also erecting a 'greenprint' for sustainable cities (Box 17.6) and investing in a fully functional 3D building (Box 17.7). A project to develop a national railway is also 'back on track' after being brought to a halt by the global financial crisis.

The United Arab Emirates has a reputation for having one of the best business climates in the region. In mid-2013, the United Arab Emirates Federation adopted a new Companies Law that comes closer to respecting international standards.

Box 17.6: Masdar City: a 'greenprint' for the city of the future

Masdar City is located about half an hour from Abu Dhabi. This artificial city is being constructed between 2008 and 2020 as a 'greenprint' for the city of the future. The aim is to build the world's most sustainable city, one capable of combining rapid urbanization with low consumption of energy, water and waste.

The city blends traditional Arabic architectural techniques with modern technology to cope with high summer temperatures and capture prevailing winds. Masdar City has one of the largest installations of photovoltaic panels on rooftops in the Middle East.

The city is sprouting around the Masdar Institute of Science and Technology, an independent research-driven, graduate-level university set up in 2007 with a focus on advanced energy and sustainable technologies. Companies are being encouraged to foster close ties with the university to accelerate the commercialization of breakthrough technologies.

By 2020, it is estimated that Masdar City will be home to 40 000 people, plus businesses, schools, restaurants and other infrastructure.

There are some who argue that the money might have been better spent on greening the country's existing cities rather than on creating an artificial one.

Source: adapted from: www.masdar.ac.ae

Box 17.7: Dubai to 'print' its first 3D building

Dubai is planning to erect the world's first fully functional three-dimensional (3D) printed building. The building will temporarily house the staff of the Museum of the Future, pending completion of permanent facilities in 2017.

Experts estimate that 3D printing technology could reduce construction time of buildings by 50–70%, labour costs by 50–80% and construction waste by 30–60%.

The office building will be printed layer by layer using a 3D printer then assembled on site in Dubai. All the furniture and structural components will also be built using 3D printing technology, combining a mixture of special reinforced concrete, glass fibre reinforced gypsum and fibre-reinforced plastic.

The scheme is backed by the National Innovation Committee. Its chairman, Mohammad Al Gergawi, considers that 'this building will be a testimony to the efficiency and creativity of 3D printing technology, which we believe will play a major role in reshaping the construction and design sectors'.

Dubai is partnering with the Chinese firm WinSun Global on this project, along with leading global architecture and engineering firms Gensler, Thornton Thomasetti and Syska Hennessy.

Source: Gulf News (2015)

It does not soften the rule, however, that prevents a majority foreign participation in local companies. It also introduces an 'Emirization' jobs programme advocating recruitment based on nationality, a measure which could curtail foreign investment, according to the Coface credit insurance[24] group.

No knowledge economy without science

The *Government Strategy* (2011–2013) lays the foundations for realizing *Vision 2021*, adopted in 2010. One of the strategy's seven priorities is to develop a competitive knowledge economy. Under this priority figures the objective of promoting and enhancing innovation and R&D, among others.

In May 2015, the Ministry of the Economy announced the launch of the Mohammed Bin Rashid Al Maktoum Business Innovation Award, in partnership with the Dubai Chamber of Commerce and Industry. This initiative crowns the United Arab Emirates' Year of Innovation and is coherent with the country's strategy of developing the pillars of a knowledge economy.

The Dubai Private Sector Innovation Index

The Dubai Chamber of Commerce and Industry is also launching two novel initiatives to nurture innovation. The first is the Dubai Private Sector Innovation Index, the first of its kind, to measure Dubai's progress towards becoming the world's most innovative city. The second initiative is the Dubai Chamber Innovation Strategy Framework, the first outside the USA; it will provide a benchmarking tool against other countries and a road map for future implementation.

Two satellites in place for Earth monitoring

The Emirates Institution for Advanced Science and Technology (EIAST, est. 2006) placed its first Earth-observation satellite in orbit in 2009, Dubai Sat 1, followed by Dubai Sat 2 in 2013. These satellites were designed and developed by the Korean company Satrec Initiative, along with a team of EIAST engineers; they are intended for urban planning and environmental monitoring, among other applications. EIAST engineers are now working with their partner on a third satellite, Khalifa Sat, due to be launched in 2017. In 2014, the government announced plans to send the first Arab spaceship to Mars in 2021. The United Arab Emirates has been advocating the creation of a pan-Arab space agency for years.

A National Research Foundation

The National Research Foundation was launched in March 2008 by the Ministry of Higher Education and Scientific Research. Individuals or teams of researchers from public and private universities, research institutes and firms may apply for competitive grants. To be approved, research proposals must survive international peer review and prove that they offer socio-economic benefits.[25]

The United Arab Emirates University is the country's premier source of scientific research. Through its research centres,[26] it has contributed significantly to the country's development of water and petroleum resources, solar and other renewable energies and medical sciences. Since 2010, the university has filed at least 55 invention patents. As of June 2014, about 20 patents had been granted to the university.[27]

The United Arab Emirates University has established strong research partnerships in areas such as oil and gas, water, health care, agricultural productivity, environmental protection, traffic

24. See: www.coface.com/Economic-Studies-and-Country-Risks/United-Arab-Emirates

25. See www.nrf.ae/aboutus.aspx

26. These include the Zayed bin Sultan Al Nahyan Centre for Health Sciences; National Water Centre; Roadway Transportation and Traffic Safety Research Centre; Centre for Public Policy and Leadership; Khalifa Center for Genetic Engineering and Biotechnology and the Centre for Energy and Environmental Research

27. See: www.uaeu.ac.ae/en/dvcrgs/research safety and the rehabilitation of concrete structures. It has established an active research network of partners in countries that include Australia, France, Germany, Japan, Republic of Korea, Oman, Qatar, Singapore, Sudan, the UK and USA.

YEMEN

No scope for science in current political quagmire

Yemen boasts several universities of repute, including the University of Sana'a (est. 1970). Yemen has never adopted a national S&T policy, though, nor allocated adequate resources to R&D.

Over the past decade, the Ministry of Higher Education and Scientific Research has organized a number of conferences to assess the reality of scientific research in the country and identify barriers to public-sector research. The ministry also launched a task force in 2007 to establish a science museum and instituted a presidential science prize in 2008. In 2014, ESCWA received a request from the ministry for assistance in establishing an STI observatory in Yemen; this endeavour has since come to a standstill in the face of the escalating conflict.

Yemen has not held parliamentary elections since 2003. The tremors of the Arab Spring led to President Saleh ceding power to his deputy, Abd Rabbuh Mansur Hadi, in February 2012, and to the establishment of a National Dialogue Conference at the initiative of the Gulf Cooperation Council. In 2015, tensions deteriorated into war between forces of the former regime and those of President Abd Rabbuh Mansur Hadi, who is backed by several Arab countries.

CONCLUSION

A need for a coherent agenda and sustainable funding

The *Arab Strategy for Science, Technology and Innovation* adopted by the Council of Ministers of Higher Education and Scientific Research in the Arab World in 2014 proposes an ambitious agenda. Countries are urged to engage in greater international co-operation in 14 scientific disciplines and strategic economic sectors, including nuclear energy, space sciences and convergent technologies such as bio-informatics and nanobiotechnology. The *Strategy* advocates involving scientists from the diaspora and urges scientists to engage in public outreach; it also calls for greater investment in higher education and training to build a critical mass of experts and staunch brain drain.

The *Strategy* nevertheless eludes some core issues, including the delicate question of who will foot the hefty bill of implementing the strategy. How can heavily indebted countries contribute to the platform? What mechanisms should be put in place to combat poverty and offer greater equity of access to knowledge and wealth at national levels? Without pondered answers to these questions, coupled with innovative out-of-the-box solutions, no strategy will be able to exploit the region's capabilities effectively.

For the *Strategy* to fly, the region's scientific community needs a coherent agenda containing a portfolio of solution-oriented scientific projects and programmes that expressly serve the region's needs, along with clearly identified sources of funding.

The events of the past few years may have stirred the cooking pot but real progress will only be measured against collective structural change at the economic, social and political levels. From the preceding country profiles, we can see that some countries are losing their winning ticket to development and progress; the motives may be economic or political but the result is the same: an exodus of experts and researchers from countries which have spent millions of dollars educating them. In many of these countries, there is a lack of a well-functioning innovation system with a clear governance and policy framework, compounded by poor ICT infrastructure that hampers access to information and opportunities to create knowledge and wealth. Governments can leverage social innovation to tackle some of these problems.

The poor state of Arab innovation systems can be attributed to many factors. The present report has highlighted, for instance, the region's low spending levels on R&D, the relatively small pool of qualified experts and research scientists and engineers, the small number of tertiary students enrolling in scientific disciplines, poor institutional support and the effects of the inimical political and social perspectives on the promotion of science.

Despite Heads of State having committed to raising GERD to 1% of GDP more than 25 years ago, not a single Arab country has yet reached that target. In most countries, the education system is still not turning out graduates who are motivated to contribute to a healthier economy. Why not? Governments should ask themselves whether the fault lies solely with the education system, or whether other impediments are stifling innovation and an entrepreneurial culture, such as a poor business climate.

How will countries of the Gulf embrace economic diversification without building a critical mass of experts, technicians and entrepreneurs? Higher education curricula are mostly fact-heavy and lecture-based, with a limited use of ICT tools and hands-on learning and little contextualization. This environment favours passive learning and examination-based assessments that measure students' ability to memorize knowledge and curriculum content rather than their ability to develop the necessary analytical skills and creativity to innovate. Teachers need to adopt novel approaches that transform them from a teleprompter into a facilitator.

There is a clear mismatch between the skills graduates are being given and labour market demand. The oversupply of university graduates and the channelling of students who perform poorly into vocational education – rather than acknowledging the key role qualified technicians play in the knowledge economy – is fuelling unemployment among tertiary graduates and leaving the market without skilled labour. The Saudi experiment since 2010 in technical and vocational education is worth noting, in this regard.

Morocco has announced its intention of making education more egalitarian. Other Arab countries could do likewise. Governments should institute scholarship schemes to give rural and poor tertiary students the same opportunities as their peers from wealthier and urban backgrounds. Recent statistics show that a fresh university graduate remains unemployed for 2–3 years on average before landing his or her first job. This situation could be turned to advantage. A national programme could be launched to recruit and train young university graduates from all academic disciplines to teach for one or two years after graduation in rural areas where there is a chronic lack of primary and secondary school teachers.

Several Arab governments are setting up observatories to improve the monitoring of their science systems through data collection and analysis. Others should follow suit, in order to monitor the effectiveness of national policies and form a network of observatories to ensure information-sharing and the development of common indicators. Some are already taking this course of action; Lebanon, for instance, is participating in a platform linking Mediterranean observatories of STI.

There is more to developing a national innovation system than putting in place material institutions. Intangible considerations and values are vital, too. These include transparency, rule of law, intolerance of corruption, reward for initiative and drive, a healthy climate for business, respect for the environment and the dissemination of the benefits of modern science and technology to the general population, including the underprivileged. Employability and placement in public insitutions should depend solely on the expertise and seniority of the individual, rather than on political considerations.

Lingering political conflicts in the Arab region have created a tendency to define national security in military terms. As a result, resources are allocated to defence and military budgets rather than to R&D that could help address the poverty, unemployment and erosion of human welfare that continue to plague the region. The countries with the highest share of military spending in GDP come from the Middle East. The resolution of political problems and the creation of collective security arrangements for the region would free up public resources that could be devoted to finding solutions to pressing problems through scientific research. Such a re-orientation would accelerate the process of economic diversification and socio-economic development.

The private sector could be encouraged to contribute to the R&D effort. We have seen how Moroccan telecom operators support public research projects in telecommunications by ceding 0.25% of their turnover to a dedicated fund. One could imagine a token amount being collected from large companies to finance R&D in their own sectors, especially in water, agriculture and energy. For the Arab States, it is imperative to accelerate the transfer of innovative technologies by developing educational large-scale pilot projects in priority areas, including renewable energy systems. This will also help to build up a critical mass of technicians in the region.

A 'value chain' is comprised of a series of interdependent components, each of which influences and is influenced by the other. Top-down approaches cannot bring about the required change. Rather, decision-makers need to create an environment that liberates the nation's dynamic forces, be they academic or economic – forces like Hayat Sindi, who is using mentors to develop an entrepreneurial culture in the region. The Arab world needs more champions of science and technology, including in the political arena, to bring about the positive change to which it aspires.

KEY TARGETS FOR ARAB COUNTRIES

- Raise GERD to at least 1% of GDP in all Arab countries;
- Raise GERD in Libya to 1% of GDP by 2020;
- Raise GERD in Morocco to 1.5% of GDP by 2025;
- RaiseTunisia's technological exports from 30% (2011) to 50% of the total by 2016;
- Produce 1 000 patents and create 200 innovative start-ups in Morocco by 2014;
- Ensure that renewable energy accounts for 12% of Lebanon's energy mix by 2020

REFERENCES

Abd Almohsen, R. (2014) Arab strategy on research collaboration endorsed. *SciDev.Net,* 25 March.

AfDB (2014) *Libya Country Re-Engagement Note 2014–2016*. African Development Bank.

AFESD *et al.* (2013) *The Unified Arab Economic Report*. Arab Fund for Economic and Social Development, with the Arab Monetary Fund, Organization of Arab Petroleum Exporting Countries and Arab League.

AFESD *et al* (2010) *The Unified Arab Economic Report*. Arab Fund for Economic and Social Development, with the Arab Monetary Fund, Organization of Arab Petroleum Exporting Countries and Arab League.

Agénor, P.R. and K. El-Aynaoui (2015) *Morocco: Growth Strategy for 2025 in an Evolving International Environment.* Policy Centre of the Office chérifien des phosphates (OCP): Rabat

Al-Droubi, Z. (2012) Syrian uprising takes toll on scientific community. *SciDev.Net,* 17 April.

Al-Hiddabi, S. (2014) Challenge Report: Oman Case Study. Paper presented to workshop run by the Korea Institute of Science and Technology Evaluation and Planning, in association with the International Science, Technology and Innovation Centre for South –South Cooperation: Melaka, Malaysia, December 2014.

Al-Soomi, M. (2012) Kuwait and economic diversification. *Gulf News*. June.

ASRT (2014) *Egyptian Science and Technology Indicators*. Egyptian Science, Technology and Innovation Observatory, Academy of Scientific Research and Technology: Cairo.

Badr, H. (2012) Egypt sets a new course for its scientific efforts. *SciDev.Net,* 17 February.

Bitar, Z. (2015) UAE to launch business innovation award. *Gulf News*, May.

Bond, M.; Maram, H.; Soliman, A. and R. Khattab (2012) *Science and Innovation in Egypt. The Atlas of Islamic World Science and Innovation: Country Case Study*. Royal Society: London.

Boumedjout, H. (2011) *EU to fund Tunisian research programme*. *Nature Middle East*. 25 October.

Bq (2014) Economic diversification reaps Qatar FDI dividends. *Bq* online. June.

Butler, D. (2011) Tunisian scientists rejoice at freedom. *Nature,* 469: 453–4, 25 January.

ESCWA (2014a) *The Broken Cycle: Universities, Research and Society in the Arab Region: Proposals for Change*. United Nations' Economic and Social Commission for Western Asia: Beirut.

ESCWA (2014b) Arab Integration: A 21st Century Development Imperative. United Nations' Economic and Social Commission for Western Asia: Beirut.

ETF (2014) *Labour Market and Employment Policy in Libya*. European Training Foundation.

Faissal, N. (2015) Le technopark de Tanger ouvrira ses portes en septembre. (The technopark in Tangers due to open in September.) *Aujourd'hui le Maroc*, 8 July.

Friedman, T. L. (2012) The other Arab Spring. *New York Times*, 7 April.

Gaub, F. (2014) *Arab Military Spending: Behind the Figures*. European Union Institute for Security Studies.

Global Financial Integrity (2013) *Illicit Financial Flows and the Problem of Net Resource Transfers from Africa: 1980-2009.* See: http://africanetresources.gfintegrity.org/index.html

Gulf News (2015) Dubai to build first fully functional 3D building in the world. Staff reporting, 30 June.

HAST (2012) *Developing Scientific Research and Innovation to Win the Battle of Competitiveness: an inventory and Key Recommendations*. Hassan II Academy of Science and Technology.

Jalal, M. A. (2014) *Science, Technology and Innovation Indicators for Sudan* (in Arabic). UNESCO: Khartoum.

Kaufmann D. A.; Kraay A. and M. Mastruzzi (2011) *World Governance Indicators*. World Bank: Washington DC.

Khatib I. A.; Tsipouri L.; Bassiakos Y. and A. Hai-Daoud (2012) Innovation in Palestinian industries: a necessity for surviving the abnormal. *Journal of the Knowledge Economy*. DOI 10.1007/s13132-012-0093-8

Le Monde (2015) Le Maroc veut construire le plus grand parc solaire du monde. *Le Monde*, 13 January.

Nour, S. (2013a) Science, technology and innovation policies in Sudan. *African Journal of Science, Technology, Innovation and Development* 5(2): 153–69.

Nour, S. (2013b) *Technological Change and Skill Development in Sudan*. Springer: Berlin (Germany), pp. 175-76.

Nour, S. (2012) *Assessment of Science and Technology Indicators in Sudan.* Science Technology & Society 17:2 (2012): 321–52.

O'Reilly, M. (2012) *Samira Rajab: the minister of many words.* Gulf News. May.

Rasooldeen, M. D. (2014) Finland to train technicians. *Arab News*, November.

Salacanin, S. (2015) Oil and gas reserves: how long will they last? *Bq magazine*, February.

Tindemans, P. (2015) *Report on STI Policy Dialogue in Egypt.* April. UNESCO: Cairo.

UNESCO and MoSC (2014) *Renewal of Policies and Systems of Science, Technology and Innovation in Sudan* (in Arabic). UNESCO and Ministry of Science and Communication: Khartoum, p. 19.

Wall Street Journal (2014) *Oil price slump strains budgets of some OPEC members.* 10 October. *See:* http://online.wsj.com

WEF (2014) *Rethinking Arab Employment: a Systemic Approach for Resource-Endowed Economies*. World Economic Forum.

Yahia, M. (2012) Science reborn in Tunisia. *Nature Middle East*. 27 January.

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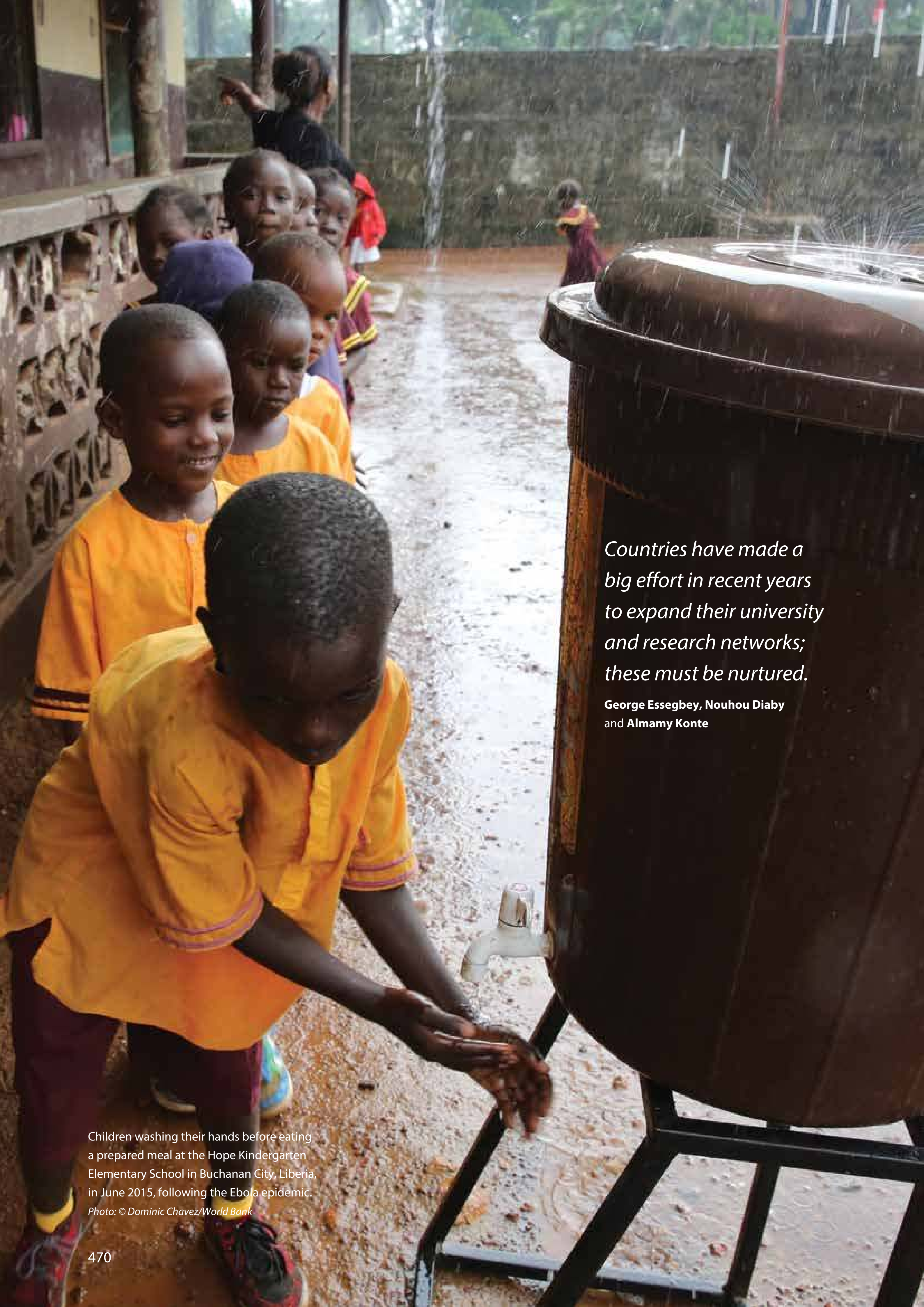


Countries have made a big effort in recent years to expand their university and research networks; these must be nurtured.

George Essegbey, Nouhou Diaby and **Almamy Konte**

Children washing their hands before eating a prepared meal at the Hope Kindergarten Elementary School in Buchanan City, Liberia, in June 2015, following the Ebola epidemic.
Photo: © Dominic Chavez/World Bank

18 · West Africa

Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo

George Essegbey, Nouhou Diaby and Almamy Konte

INTRODUCTION

A drive to achieve middle-income status by 2030

Most West African countries are striving to achieve lower or upper middle-income status[1] within the next 15 years. This goal is enshrined in the current development plans and economic policies of Côte d'Ivoire, Gambia, Ghana, Liberia, Mali, Senegal and Togo, for instance. Nigeria even plans to join the world's top 20 economies by 2020. Yet, for two-thirds of West African countries, middle-income status remains an elusive goal: annual GDP per capita remains below US$ 1 045 in all of Benin, Burkina Faso, Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Sierra Leone and Togo.

Countries' development plans tend to have three main thrusts: wealth creation, greater social equity and more sustainable development. In their quest for middle-income status, they are giving priority to improving governance practices, creating a more business-friendly climate, stronger health and agricultural systems, modern infrastructure and a skilled labour force. These plans reflect a desire to exploit the resources which form the backbone of their economies in a more sustainable manner and a determination to diversify and modernize the economy. None of this will be possible without a skilled labour force and recourse to science, technology and innovation (STI).

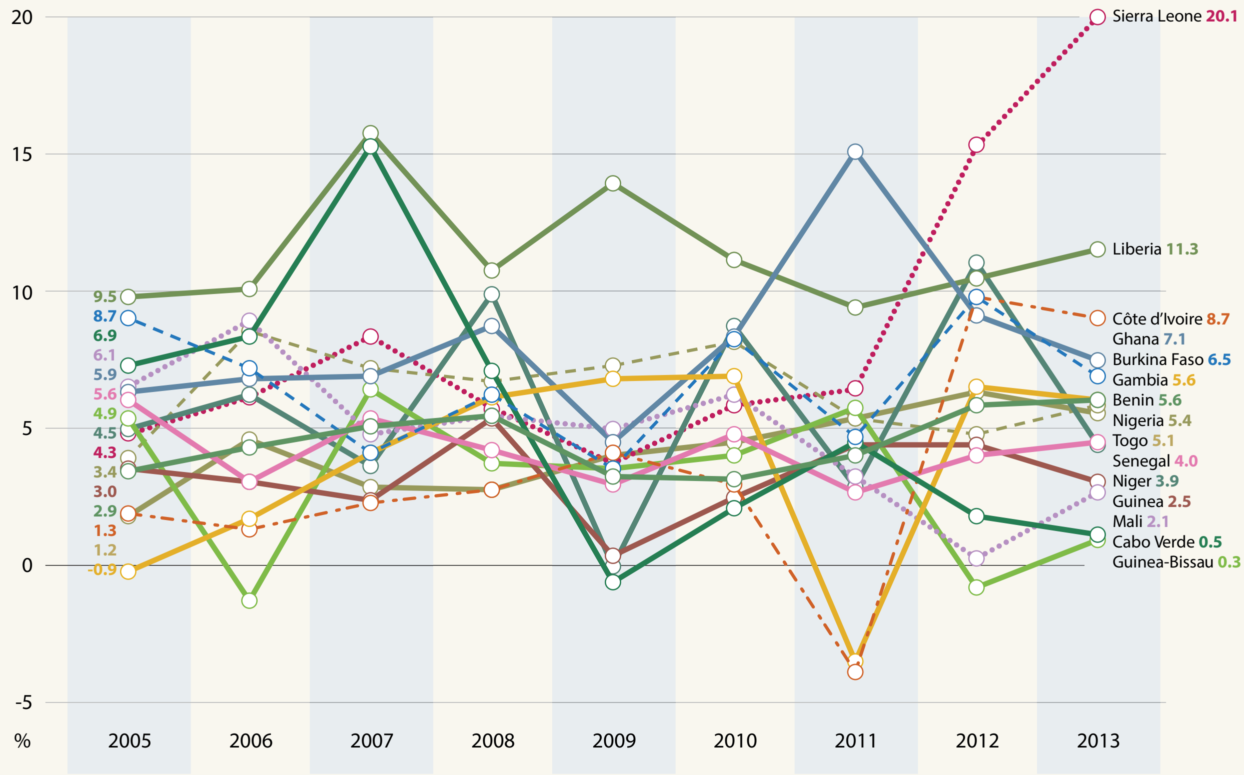
Strong growth in recent years, despite a series of crises

The Economic Community of West African States (ECOWAS) has experienced strong economic growth in recent years, despite a series of crises.

In Mali, a Tuareg rebellion in January 2012 attempted to establish an independent homeland in the north through an alliance with jihadist groups. The situation has stabilized since the government appealed for French intervention in January 2013 but remains fragile. The conflict caused Mali's economy to shrink by 0.4% in 2012, after six years of sustained growth of 5% on average (Figure 18.1).

1. Five countries have already achieved lower middle-income status, namely: Cabo Verde, Côte d'Ivoire, Ghana, Nigeria and Senegal. The next step will be upper middle-income status.

Figure 18.1: **Economic growth in West Africa, 2005–2013** (%)



Source: World Bank's World Development Indicators, September 2014.

Guinea-Bissau suffered a military coup d'état in April 2012, prompting the African Union to impose sanctions which were lifted two years later following the election of President José Mario Vaz.

Côte d'Ivoire is still picking up the pieces after its civil war ended with the arrest of the ex-president for war crimes in April 2011. After stagnating for years, Côte d'Ivoire's economy rebounded by 9% in 2013.

Meanwhile, in the north of Africa's most populous country, the Boko Haram sect (literally 'books are forbidden') pursues its reign of terror against the Nigerian population, with growing incursions across the border into Cameroon and Niger. Nigerians can at least rejoice at the smooth handover of power from incumbent president Goodluck Jonathan to his successor Muhammadu Buhari after the election results were announced on 31 March 2015.

Farther north, in Burkina Faso, a popular revolt put an end to the 27-year rule of President Blaise Compaoré on 30 October 2014, after he tried to modify the Constitution in order to run for a fifth term. Former diplomat Michel Kafando has been designated interim president by consensus and charged with organizing a general election in November 2015.

In Guinea, Liberia and Sierra Leone, the Ebola epidemic has been a tragic reminder of the chronic underinvestment in West African health systems. Between March and December 2014, 8 000 people died, a mortality rate of about 40%. There has been a growing tide of solidarity. In September, Cuba dispatched hundreds of doctors and nurses to the afflicted countries. A month later, the East African Community sent its own contingent of 600 health professionals, including 41 doctors, to combat the epidemic. They were joined in early December by 150 volunteer health professionals from Benin, Côte d'Ivoire, Ghana, Mali, Niger and Nigeria, as part of a joint initiative by ECOWAS and its specialized agency, the West African Health Organisation. The European Union, African Union, USA and others have also pitched in with funding and other forms of support. The year before Ebola struck, Liberia and Sierra Leone had experienced remarkable growth of 11% and 20% respectively. Ebola could set these fragile economies back years (Figure 18.1).

Structural weaknesses masked by strong growth

Despite these crises, the ECOWAS Commission is optimistic about the subregion's prospects for growth. It projects an even better performance in 2014 (7.1% growth) than in 2013 (6.3%). This high growth rate nevertheless conceals serious structural weaknesses. For decades, West African economies have relied almost entirely on revenue from raw commodities: about 95% of Nigeria's export revenue is derived from crude oil and natural gas; gold and cocoa alone account for about 53% of Ghana's exports and nearly three-quarters of Mali's export earnings come from cotton (Figure 18.2). When raw materials are extracted or grown in West Africa but processed on other continents, this deprives the subregion of industries and jobs. Despite this axiom, West African countries have so far failed to diversify their economies and to tap export earnings from value-added and manufactured products.

It is true that some countries have made a start. Côte d'Ivoire, Ghana, Guinea, Nigeria and Senegal, for instance, have industries producing value-added goods. To enhance value addition and strengthen the raw material base of industries, these countries have all set up research institutes to transform raw products into semi-processed or processed goods. Both Ghana and Nigeria have also set up institutes specializing in aeronautics, nuclear energy, chemistry and metallurgy. The first technology parks and cybervillages are emerging in these countries (ECOWAS, 2011a).

Could Ghana fall prey to the 'oil curse?' A recent study by the Institute of Statistical, Social and Economic Research at the University of Ghana ponders whether 'the increased importance of oil in GDP [since petroleum exports began in 2011] signals the risk of Ghana becoming oil-dependent. [...] The advent of oil production seems to be changing the pattern of the country's exports,' the study observes (see Figure 19.1). 'Is Ghana teetering toward an oil-dominant country, or might the proceeds be employed wisely to diversify the economy?' (ISSER, 2014)

Economic diversification hampered by a skills shortage

One handicap to diversifying the economy is the shortage of skilled personnel, including technicians, in fast-growing sectors such as mining, energy, water, manufacturing, infrastructure and telecommunications. The lack of skilled personnel also impinges on the efficiency of national health systems and agriculture.

In this context, the launch of the African Centres of Excellence project in April 2014 by the World Bank comes as a welcome addition to the education matrix. Eight governments[2] are to receive almost US$ 150 million in loans to fund research and training at 19 of the subregion's best universities (Table 18.1). The Association of African Universities will be responsible for co-ordination and knowledge-sharing among all 19 universities and has received World Bank funding for the purpose.

For all its virtues, the African Centres of Excellence project cannot be a substitute for national investment. Currently, just three[3] West African countries devote more than 1% of

2. Nigeria (US$ 70 million), Ghana (US$ 24 million), Senegal (US$ 16 million), Benin, Burkina Faso, Cameroon and Togo (US$ 8 million each). Gambia will also receive a US$ 2 million loan and a US$ 1 million grant for short-term training.

3. Data are unavailable for Nigeria.

Figure 18.2: **Top three export products in Africa, 2012**

Algeria – Petroleum & other oils, crude (45.0%), natural gas in gaseous state (20.0%), light oils and preparations (8.7%)

Angola – Petroleum & other oils, crude (96.8%)

Benin – Cotton (19.0%), petroleum oils or bituminous minerals (13.7%), gold (13.4%)

Botswana – Unworked diamonds (74.3%), other non-industrial diamonds (7.2%), gold in semi-manufactured forms (5.4%)

Burkina Faso – Cotton (44.9%), gold in unwrought forms (29.4%), gold in semi-manufactured forms (5.4%)

Burundi – Unroasted coffee (58.0%), black tea (12.2%), niobium, tantalum, vanadium ores & concentrates (9.0%)

Cabo Verde – Mackerel (16.5%), skipjack or stripe-bellied bonito (15.4%), yellowfin tunas (14.2%)

Cameroon – Petroleum & other oils, crude (48.1%), cocoa beans (9.0%), tropical woods (7.7%)

Central African Rep. – Unsorted diamonds (32.3%), tropical wood (26.6%), cotton (14.0%)

Chad – Petroleum & other oils, crude a preparations (97.0%)

Comoros – Cloves (56.1%), floating vessels for breaking up (21.2%), essential oils (9.8%)

Congo. Rep. – Petroleum & other oils, crude (87.1%)

Congo. Dem. Rep. – Cathodes (43.9%), unrefined copper (13.2%), petroleum & other oils, crude (13.2%)

Côte d'Ivoire – Cocoa beans (31.8%), petroleum & other oils, crude (12.3%), natural rubber (7.2%)

Djibouti – Live animals (23.0%), sheep (18.1%), goats (15.6%)

Egypt – Petroleum & other oils, crude (24.0%), liquefied natural gas (11.1%),

Equatorial Guinea – Petroleum & other oils, crude (73.6%), liquefied natural gas (19.8%)

Eritrea – Gold (88.0%), silver (4.9%)

Ethiopia – Unroasted coffee (39.5%), sesamum seeds (19.7%), fresh cut flowers (10.2%)

Gabon – Petroleum & other oils, crude (85.4%), manganese ores & concentrates (6.7%)

Gambia – Wood (48.6%), cashew nuts (16.2%), petroleum & other oils (6.5%)

Ghana – Gold (36.0%), cocoa beans and paste (16.5%), petroleum & other oils, crude (22.0%)

Guinea – Gold (40.5%), bauxite (34.0%), alumine (9.0%)

Guinea-Bissau – Cashew nuts (83.9%)

Kenya – Black tea (20.0%), fresh cut flowers (12.1%), unroasted coffee (5.9%)

Lesotho – Diamonds (45.5%), men's/boys' cotton trousers & shorts (13.4%), women's/girls' synthetic trousers & shorts (6.1%)

Liberia – Iron ores & concentrates (21.1%), natural rubber (19.3%), tankers (12.3%)

Libya – Petroleum & other oils, crude (88.4%), natural gas in gaseous state (5.6%)

Madagascar – Cloves (15.8%), shrimps & prawns (7.2%), titanium ores & concentrates (5.5%)

Malawi – Tobacco (50.1%), natural uranium & its compounds (10.4%), raw sugar cane (8.0%)

Mali – Cotton (72.7%), sesamum seeds (8.8%)

Mauritania – Iron ores and concentrates (46.7%), copper ores and concentrates (15.6%), octopus (10.5%)

Mauritius – Tunas, skipjack & bonito (15.3%), solid cane or beef sugar (10.5%), cotton t-shirts & the like (7.4%)

Morocco – Phosphoric acid and polyphosphoric (8.2%), ignition wiring sets and other wiring sets of a type used for vehicles, aircrafts, ships (6.1%), diammonium hydrogenorthosphosphate (4.5%)

Mozambique – Aluminium, not alloyed (28.8%), light oils & preparations (12.1%), liquefied natural gas (5.4%)

Namibia – Unworked diamonds (30.1%), unrefined copper (13.4%), natural uranium & its compounds (13.2%)

Niger – Natural uranium & its compounds (62.2%), light oils & preparations (12.1%), live animals (6.0%)

Nigeria – Petroleum & other oils, crude (84.0%), liquefied natural gas (10.8%)

Rwanda – Niobium, tantalum, vanadium ores & concentrates (23.7%), unroasted coffee (23.5%), tin ores & concentrates (19.2%)

Sao Tome & Principe – Cocoa beans (47.6%), wristwatches (9.2%), jewellery (6.4%)

Senegal – Petroleum & other oils (20.8%), inorganic chemical elements, oxides & halogen salts (12.0%), fresh & frozen fish (9.0%)

Seychelles – Tunas, skipjack & bonito (52.5%), bigeye tunas (13.2%), yellowfin tunas (7.1%)

Sierra Leone – Iron ores & concentrates (45.2%), titanium ores & concentrates (16.4%), unworked diamonds (12.1%)

Somalia – Sheep (29.4%), goats (28.2%), live bovine animals (17.3%)

South Africa – Gold (11.6%), iron ores & concentrates (7.6%), platinum (6.6%)

South Sudan – Petroleum & other oils, crude (99.6%)

Sudan – Petroleum & other oils, crude (65.6%), Sheep (10.6%), sesamum seeds (4.2%)

Swaziland – Raw sugar cane (17.4%), odoriferous substances used in food & beverages (14.8%), iron ores & concentrates (10.9%)

Tanzania – Precious metal ores & concentrates (11.7%), tobacco (11.5%), unroasted, not decaffeinated coffee (6.6)

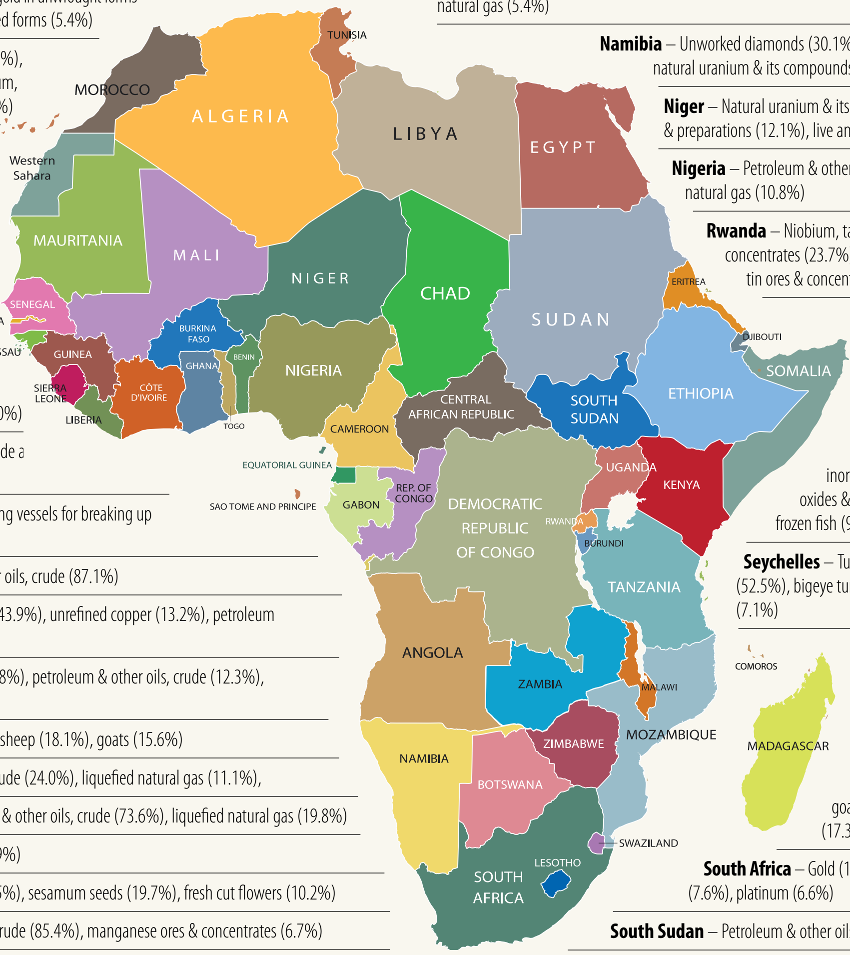
Togo – Gold (12.1%), natural calcium phosphates, phosphatic chalk (11.7%), light oils & preparations (10.3%)

Tunisia – Petroleum & other oils, crude (11.2%), ignition wiring sets and other wiring sets of a type used for vehicles, aircrafts, ships (6.2%); men's/boys' cotton trousers and shorts (4.3%)

Uganda – Unroasted, not decaffeinated coffee (30.6%), cotton (5.6%), tobacco (5.5%)

Zambia – Cathodes (47.6%), unrefined copper (26.1%), maize, excl. seed (5.0%)

Zimbabwe – Tobacco (30.8%), ferro-chromium (11.6%), cotton (9.6%)



Note: Data for Ghana are for 2013.

Source: ADB *et al.* (2014), Table 18.7; for Ghana: calculated for 2013 from ISSER (2014)

GDP to higher education: Ghana and Senegal (1.4%) and Mali (1.0%). In Liberia, the proportion is even lower than 0.3% (see Table 19.2). Up to now, the priority has been to achieve the Millennium Development Goal of universal primary education by 2015. Low investment in higher education has led to a surge in private universities over the past decade, which now represent more than half of all universities in some countries (ECOWAS, 2011a).

Table 18.1: **The African Centres of Excellence Project, 2014**

	Centre of excellence	Lead institution
Benin	Applied Mathematics	University of Abomey-Calavi
Burkina Faso	Water, Energy, Environmental Sciences and Technologies	International Institute of Water and Environmental Engineering (2iE)
Cameroon	Information and Communication Technologies	University of Yaoundé
Ghana	Training Plant Breeders, Seed Scientists and Technologists	University of Ghana
	Cell Biology of Infectious Pathogens	University of Ghana
	Water and Environmental Sanitation	Kwame Nkrumah University of Science and Technology
Nigeria	Agricultural Development and Sustainable Environment	Federal University of Agriculture
	Dryland Agriculture	Bayero University
	Oil Field Chemicals	University of Port Harcourt
	Science, Technology and Knowledge	Obafemi Awolowo University
	Food Technology and Research	Benue State University
	Genomics of Infectious Diseases	Redeemers University
	Neglected Tropical Diseases and Forensic Biotechnology	Ahmadu Bello University
	Phytomedicine Research and Development	University of Jos
	Reproductive Health and Innovation	University of Benin, Nigeria
	Materials	African University of Science and Technology
Senegal	Maternal and Infant Health	Cheikh Anta Diop University
	Mathematics, Informatics and Information and Communication Technologies	University of Gaston Berger, St Louis
Togo	Poultry Sciences	University of Lomé

Source: World Bank

Centres of excellence: a problem shared is a problem halved

Most West African scientists currently work in isolation from their peers even within the same country. The World Bank scheme is coherent with *Africa's Science and Technology Consolidated Plan of Action* covering 2006–2013, which called for the establishment of regional networks of centres of excellence and for a greater mobility of scientists across the continent.

West Africa is participating in several of these networks. Ouagadougou (Burkina Faso) hosts the African Biosafety Network of Expertise (Box 18.1) and the Senegalese Institute for Agricultural Research in Dakar is one of the four nodes of the pan-African biosciences network (see Box 19.1). In addition, Senegal and Ghana host two of the five African Institutes of Mathematical Sciences (see Box 20.4).

In 2012, the West African Economic and Monetary Union (WAEMU) designated 14 centres of excellence in the region (Table 18.2). This label entitles these institutions to financial support from WAEMU for a two-year period. Within the framework of its *Policy on Science and Technology* (see p. 476), ECOWAS intends to establish several centres of excellence of its own on a competitive basis.

Table 18.2: **The WAEMU Centres of Excellence, 2012**

	Centre of excellence	City
Burkina Faso	Centre for Research in Biological and Food Science and Nutrition	Ouagadougou
	Higher Institute of Population Sciences	Ouagadougou
	International Centre for Research and Development into Animal Husbandry in Subtropical Zones	Bobo-Dioulasso
	International Institute of Water and Environmental Engineering	Ouagadougou
Côte d'Ivoire	National School of Statistics and Applied Economics	Abidjan
Mali	West African Network of Education Research	Bamako
Niger	Regional Centre for Training and Applications in Agro-meteorology and Operational Hydrology	Niamey
	Regional Specialized Teaching Centre in Agriculture	Niamey
Senegal	African Centre for Higher Management Studies	Dakar
	Multinational Higher School of Telecommunications	Dakar
	School of Veterinary Science and Medicine	Dakar
	Africa Rice Centre	Saint-Louis
	Higher Institute of Management	Dakar
Togo	African School of Architecture and Urban Planning	Lomé

Source: WAEMU

Box 18.1: **The African Biosafety Network of Expertise**

The African Biosafety Network of Expertise was established in Ouagadougou on 23 February 2010 with the signing of a host agreement between NEPAD and the Government of Burkina Faso. The network serves as a resource for regulators dealing with safety issues related to the introduction and development of genetically modified organisms. In addition to providing regulators with access to policy briefs and other relevant information online in English and French, the network organizes national and subregional workshops on specific topics.

For instance, one-week biosafety courses for African regulators were run by the network in Burkina Faso in November 2013 and in Uganda in July 2014, in partnership with the University of Michigan (USA). Twenty-two regulators from Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Uganda and Zimbabwe took part in the latter course.

In April 2014, the network ran a training workshop in Nigeria at the request of the Federal Ministry of Environment for 44 participants drawn from government ministries, regulatory agencies, universities and research institutions. The aim was to strengthen the regulatory capacity of institutional biosafety committees. This training was considered important to ensure continued regulatory compliance for ongoing confined field trials and multilocation trials for Maruca-resistant cowpea and biofortified sorghum. The workshop was run in partnership with the International Food Policy Research Institute's Program for Biosafety Systems.

From 28 April to 2 May 2014, Togo's Ministry of Environment and Forest Resources organized a stakeholders' consultative workshop to validate Togo's revised biosafety law. Around 60 participants took part, including government officials, researchers, lawyers, biosafety regulators and civil society representatives; the workshop was chaired by a member of the National Biosafety Committee. The aim of the draft bill was to align Togo's biosafety law signed in January 2009 with international biosafety regulations and best practices, especially the *Nagoya Kuala Lumpur Supplementary Protocol on Liability and Redress* that Togo had signed in September 2011. The validation workshop was a critical step before the new bill could be tabled at the National Assembly for adoption later that year.

In June 2014, the network organized a four-day study tour to South Africa for ten regulators and policy-makers from Burkina Faso, Ethiopia, Kenya, Malawi, Mozambique and Zimbabwe. The main objective was to allow them to interact directly with their peers and industrial practitioners in South Africa. The study tour was organized under the auspices of the NEPAD Planning and Coordinating Agency, in partnership with the Southern Africa Network for Biosciences (SANBio), see Box 19.1).

The African Biosafety Network of Expertise was conceptualized in *Africa's Science and Technology Consolidated Plan of Action* (2005) and fulfils the recommendation of the High-Level African Panel on Modern Biotechnology, entitled *Freedom to Innovate* (Juma and Serageldin, 2007). The network is funded by the Bill and Melinda Gates Foundation.

Source: www. nepadbiosafety.net

Source of map: 2013 African Biosafety Network of Expertise

A REGIONAL VISION FOR SCIENCE AND TECHNOLOGY

A roadmap for more effective development

Regional integration can help accelerate development in West Africa. The *Vision 2020* document[4] adopted by ECOWAS member states in 2011 is consistent with the continent's long-term objective of creating an African Economic Community (Box 18.2). *Vision 2020* aspires to 'create a borderless, prosperous and cohesive region built on good governance and where people have the capacity to access and harness its enormous resources through the creation of opportunities for sustainable development and environmental preservation… We envision, by 2020, an environment in which the private sector will be the primary engine of growth and development' (ECOWAS, 2011b).

Vision 2020 proposes a road map for improving governance, accelerating economic and monetary integration and fostering public–private partnerships. It endorses the planned harmonization of investment laws in West Africa and suggests pursuing 'with vigour' the creation of a regional investment promotion agency. Countries are urged to promote efficient, viable small and medium-sized enterprises (SMEs) and to expose traditional agriculture to modern technology, entrepreneurship and innovation, in order to improve productivity.

The agriculture sector suffers from chronic underinvestment in West Africa. Only Burkina Faso, Mali, Niger and Senegal have so far raised public expenditure to 10% of GDP, the target fixed by the *Maputo Declaration* (2003). Gambia, Ghana and Togo are on the threshold of reaching this target. Nigeria devotes 6% of GDP to agriculture and the remaining West African countries less than 5% (see Table 19.2).

Other underdeveloped areas are the water, sanitation and electricity sectors, which hold potential for public–private partnerships. The situation is most urgent in Benin, Ghana, Guinea and Niger, where less than 10% of the population enjoys improved sanitation. Although people have greater access to clean water than to sanitation, this basic commodity still eludes more than half of the population in most countries. Access to electricity varies widely, from 13% in Burkina Faso to 72% in Ghana (see Table 19.1).

Internet penetration has been excruciatingly slow in West Africa, contrary to mobile phone subscriptions. As of 2013, 5% of the population or less had access to internet in Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Liberia, Mali, Niger, Sierra Leone and Togo. Only Cabo Verde and Nigeria could provide one in three citizens with internet connections (see Table 19.1).

4. See the ECOWAS Community Development Programme: www.cdp-pcd.ecowas.int

A framework for co-ordinating the region's STI policies

Why has the research sector had so little impact on technological progress in West Africa? Apart from obvious factors like underinvestment, this situation has resulted from the relatively low political commitment to STI on the part of individual countries. There is a lack of:

- national research and innovation strategies or policies with a clear definition of measurable targets and the role to be played by each stakeholder;
- involvement by private companies in the process of defining national research needs, priorities and programmes; and
- institutions devoted to innovation that can make the link between research and development (R&D).

The low impact of science and technology (S&T) in West Africa has also resulted from the differences in education systems, the lack of convergence among research programmes and the low level of exchanges and collaboration between universities and research institutions. The centres of excellence cited earlier should help to foster collaboration and the dissemination of research results, as well as a greater convergence among research programmes. In education, the three-tiered degree system (bachelor's –master's–PhD) has now been generalized to most West African countries. In the case of WAEMU countries, this is largely thanks to the Support to Higher Education, Science and Technology Project, funded by a grant from the African Development Bank. Between 2008 and 2014, WAEMU invested US$ 36 million in this reform.

The *ECOWAS Policy on Science and Technology* (ECOPOST) is the logical next step. Adopted in 2011, it is an integral part of *Vision 2020*. ECOPOST provides a framework for member states wishing to improve – or elaborate for the first time – their own national policies and action plans for STI. Importantly, ECOPOST includes a mechanism for monitoring and evaluating the policy's implementation, an aspect often overlooked. Nor does it neglect funding. It proposes creating a solidarity fund which would be managed by a directorate within ECOWAS to help countries fund investment in key institutions and improve education and training; the fund would also be used to attract foreign direct investment (FDI). As of early 2015, the fund had not yet been established.

The regional policy advocates the development of a science culture in all sectors of society, including through science popularization, the dissemination of research results in local and international journals, the commercialization of research results, greater technology transfer, intellectual property protection, stronger university–industry ties and the enhancement of traditional knowledge.

Box 18.2: An African Economic Community by 2028

The Abuja Treaty (1991) established a calendar for creating an African Economic Community by 2028. The first step was to establish regional economic communities in parts of Africa where these were still lacking. The next target is to establish a free trade area and customs union in each regional economic community by 2017 then across the entire continent by 2019. A continent-wide African Common Market is to become operational in 2023. The last stage will consist in establishing a continent-wide economic and monetary union and parliament by 2028, with a single currency to be managed by the African Central Bank.

The six regional pillars of the future African Economic Community are the following regional communities:

- Economic Community of West African States (ECOWAS): 15 states, population of *circa* 300 million;
- Economic Community of Central African States (ECCAS), 11 states, population of *circa* 121 million;
- Southern African Development Community (SADC), 15 states, population of *circa* 233 million;
- East African Community (EAC), 5 states, population of *circa* 125 million;
- Common Market for Eastern and Southern Africa (COMESA), 20 states, population of *circa* 406 million;
- Intergovernmental Authority on Development (IGAD), 8 states, population of *circa* 188 million.

Some countries belong to more than one economic community, creating overlap (see Annex 1 for the membership of these regional blocs). Kenya, for instance, is a member of COMESA, EAC and IGAD. There are also smaller regional blocs. One example is the West African Economic and Monetary Union grouping Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal and Togo.

ECOWAS has launched a common passport to facilitate travel and finance ministers agreed in 2013 to launch a Common External Tariff in 2015 to discourage wide price differentials and smuggling across the region.

In 2000, nine COMESA members formed a free trade area: Djibouti, Egypt, Kenya, Madagascar, Malawi, Mauritius, Sudan, Zambia and Zimbabwe. They were later joined by Burundi and Rwanda (2004), Comoros and Libya (2006) and by the Seychelles in 2009. In 2008, COMESA agreed to expand its free-trade zone to include EAC and SADC members. The COMESA–EAC–SADC Tripartite Free Trade Agreement was signed on 10 June 2015 in Sharm-El-Sheikh (Egypt).

On 1 July 2010, the five EAC members formed a common market grouping Burundi, Kenya, Rwanda, Tanzania and Uganda. In 2014, Rwanda, Uganda and Kenya agreed to adopt a single tourist visa. Kenya, Tanzania and Uganda have also launched the East African Payment System. The region is also investing in a standard gauge regional rail, roads, energy and port infrastructure to strengthen links to Mombasa and Dar es Salaam. Intra-EAC trade grew by 22% in 2012 over the previous year. On 30 November 2013, the EAC countries signed a Monetary Union Protocol with the aim of establishing a common currency within 10 years.

Pending the single African currency, 14 countries currently use the West African CFA and Central African CFA currency (in place since 1945), which is indexed on the euro managed by the European Central Bank. The indexation of the CFA on a strong currency favours imports over exports. Five countries currently use the South African Rand: Lesotho, Namibia, South Africa, Swaziland and Zimbabwe.

Source: AfDB *et al.* (2014); other information compiled by authors

ECOPOST encourages countries *inter alia* to:

- raise gross domestic expenditure on R&D (GERD) to 1% of GDP, as recommended by the African Union a decade ago; currently, it averages 0.3% in West Africa;
- define their own research priorities, so that researchers are working on topics of national interest rather than those proposed by donors;
- create a national S&T fund which would allocate funds to research projects on a competitive basis;
- establish science and innovation prizes;
- define a harmonized regional status for researchers;
- put in place a national fund for local innovators which would also help them protect their intellectual property rights;
- adapt university curricula to local industrial needs;
- develop small research and training units in key industrial fields, such as lasers, fibre optics, biotechnology, composite materials and pharmaceuticals;
- equip research laboratories, including with ICTs;

- establish science and technology parks and business incubators;
- help companies specializing in electronics to set up business in their country and develop the use of satellites and remote sensing for telecommunications, environmental monitoring, climatology, meteorology, etc.;
- develop a national capacity to manufacture computer hardware and design software;
- facilitate the spread of modern IT infrastructure to foster teaching, training and research;
- incite the private sector to finance research and technology through tax incentives and related measures;
- create networks between universities, research institutions and industry to promote collaboration;
- foster clean, sustainable sources of energy and the development of local construction materials;
- establish national and regional databases on R&D activities.

Countries are also encouraged to work with the ECOWAS Commission to improve data collection. Of the 13 countries which participated in the first phase[5] of the African Science, Technology and Innovation Indicators Initiative (ASTII), just four from ECOWAS contributed to ASTII's first collection of R&D data for publication in the *African Innovation Outlook* (2011): Ghana, Mali, Nigeria and Senegal (NPCA, 2011).

5. ASTII was launched in 2007 by the African Union's New Partnership for Africa's Development (NEPAD), in order to improve data collection and analysis on R&D.

ECOWAS was barely more visible in the second *African Innovation Outlook*, with just six countries contributing R&D data, out of 19 across the continent: Burkina Faso, Cabo Verde, Ghana, Mali, Senegal and Togo (NPCA, 2014). Nigeria was totally absent and only Ghana and Senegal provided a full set of data for all four performance sectors, which is why they alone feature in Figure 18.5.

Subregional training workshops were organized for countries by ECOWAS in 2013 and 2014 on STI indicators and how to draft research proposals.

ECOWAS has taken other steps recently to tackle the lack of technological impact of the research sector:

- In 2012, the ministers in charge of research adopted the *ECOWAS Research Policy* (ECORP) while meeting in Cotonou;
- In 2011, ECOWAS created the West Africa Institute within a public–private partnership (Box 18.3).

TRENDS IN EDUCATION

Efforts to generalize primary education are paying off

One of West Africa's toughest challenges will be to educate and train young people and develop a highly skilled labour force, particularly in science and engineering. Illiteracy remains a major hurdle to expanding science education: only two out of three young people (62.7%) between the ages of 15 and 24 are literate, with the notable exception of Cabo Verde (98.1%). The proportion of literates is as low as one person in four in Niger (23.5%).

Box 18.3: **The West Africa Institute**

The West Africa Institute was established in Praia (Cabo Verde) in 2010 to provide the missing link between policy and research in the regional integration process. The institute is a service provider, conducting research for regional and national public institutions, the private sector, civil society and the media. The think tank also organizes political and scientific dialogues between policy-makers, regional institutions and members of civil society.

There are ten research themes: the historical and cultural bases of regional integration; citizenship; governance; regional security; economic challenges to market integration in West Africa; new ICTs; education; the problem of shared resources (land, water, minerals, coastal and maritime security); funding of NGOs in West Africa; and migration.

The idea for the West Africa Institute emerged from 15 research workshops on the theme of regional integration organized in the ECOWAS member states by UNESCO's Management of Social Transformations programme.

In 2008, the Summit of Heads of State and Government of ECOWAS in Ouagadougou (Burkina Faso) unanimously endorsed the idea to create the West Africa Institute.

In 2009, UNESCO's General Conference established the West Africa Institute as one of its category 2 institutes, which means that it functions under the auspices of UNESCO. A year later, the Government of Cabo Verde passed a law establishing the institute in the capital.

The institute is the fruit of a public–private partnership involving ECOWAS, WAEMU, UNESCO, the pan-African Ecobank and the Government of Cabo Verde.

Source: westafricainstitute.org

The considerable efforts made at the primary level are paying off, with the average enrolment rate having risen from 87.6% to 92.9% between 2004 and 2012 (Table 18.3). According to the *ECOWAS Annual Report* (2012), enrolment has increased by as much as 20% since 2004 in four countries: Benin, Burkina Faso, Côte d'Ivoire and Niger.

However, in most West African countries, one in three children do not complete the primary cycle. The share is even higher than 50% in Burkina Faso and Niger. In 2012, there were an estimated 17 million children out of school in ECOWAS countries. Although this represents a 3% improvement over the previous decade, this figure pales in comparison to that for sub-Saharan Africa as a whole, where the drop-out rate has fallen by 13%. Cabo Verde and Ghana are the exceptions to the rule, both having a high completion rate (over 90%). Ghana has achieved almost 100% enrolment at primary level, largely thanks to the government's free school meals programme. Five out of six ECOWAS countries reported a higher percentage of qualified primary teachers in 2012 than eight years earlier; especially notable are improvements in Senegal (+15%) and Cabo Verde (+13%).

Table 18.3: **Gross enrolment in ECOWAS countries, 2009 and 2012 (%)**

Share of population at all levels of education

	Primary (%)		Secondary (%)		Tertiary (%)	
	2009	2012	2009	2012	2009	2012
Benin	114.87	122.77	–	54.16^{+1}	9.87	12.37^{-1}
Burkina Faso	77.68	84.96	20.30	25.92	3.53	4.56
Cabo Verde	111.06	111.95	85.27	92.74	15.11	20.61
Côte d'Ivoire	79.57	94.22	–	39.08^{+1}	9.03	4.46
Gambia	85.15^{+1}	85.21	58.84	–	–	–
Ghana	105.53	109.92	58.29	58.19	8.79	12.20
Guinea	84.60	90.83	34.29^{-1}	38.13	9.04	9.93
Guinea-Bissau	116.22^{+1}	–	–	–	–	–
Liberia	99.64	102.38^{-1}	–	45.16^{-1}	9.30^{+1}	11.64
Mali	89.25	88.48	39.61	44.95^{+1}	6.30	7.47
Niger	60.94	71.13	12.12	15.92	1.45	1.75
Nigeria	85.04*	–	38.90*	–	–	–
Senegal	84.56	83.79	36.41^{+1}	41.00^{-1}	8.04	–
Togo	128.23	132.80	43.99^{-1}	54.94^{-1}	9.12^{+1}	10.31

*estimation by UNESCO Institute for Statistics

-n/+n = data refer to n years before or after reference year

Source: UNESCO Institute for Statistics, May 2015

The challenge now will be to raise the enrolment rate at secondary level from 45.7% in 2011, albeit with marked differences from one country to another: just one in four children from Niger and Burkina Faso attend secondary school, whereas, in Cabo Verde, enrolment has shot up to 92.7% (2012).

To promote girls' education, ECOWAS established the ECOWAS Gender Development Centre in Dakar in 2003. Moreover, ECOWAS provides scholarships for girls from disadvantaged families to enable them to pursue their technical or vocational education. The *ECOWAS Annual Report* for 2012 states that the number of girls receiving scholarships in each country had doubled from five to ten or more by 2012 in some countries.

Growing student rolls but universities remain elitist

On average, the gross enrolment rate for tertiary education in West Africa was 9.2% in 2012. Some countries have made impressive progress, such as Cabo Verde between 2009 (15.1%) and 2012 (20.6%). In others, a university education remains elusive: the figures for Niger and Burkina Faso have stagnated at 1.7% and 4.6% of school leavers respectively.

University rolls are rising but this needs placing in a context of strong population[6] growth. The notable exception is Côte d'Ivoire, where student numbers have been a casualty of the violence and political uncertainty arising from the disputed 2010 election, which prompted the closure of universities and eventually unseated President Gbagbo.

It is difficult to draw conclusions for West Africa as a whole, given the patchy data. The available data nevertheless reveal some interesting trends. For instance, student rolls have surged in recent years in Burkina Faso and Ghana (Table 18.4). Burkina Faso shows the particularity, moreover, of having one of the subregion's highest ratios of PhD students: one in 20 graduates goes on to enroll in a PhD. The number of PhDs in engineering fields remains low: 58 in Burkina Faso and 57 in Ghana in 2012, compared to 36 in Mali and just one in Niger in 2011. Of note is that Ghana is the only country with a critical mass of PhD students in agriculture (132 in 2012), a situation which bodes ill for agricultural development in the subregion. Likewise, Burkina Faso trains a much greater number of PhDs in the field of health than its neighbours; women tend to be most attracted to health sciences: they represent one in three of these PhD candidates in Burkina Faso and Ghana, compared to about one in five in science and engineering (Figure 18.3).

6. The population is growing by more than 3% each year in the Sahelian countries of Mali and Niger and by more than 2.3% in all but Sierra Leone (1.8%) and Cabo Verde (0.95%). See Table 19.1

Table 18.4: **Tertiary enrolment in West Africa, 2007 and 2012 or nearest available year**

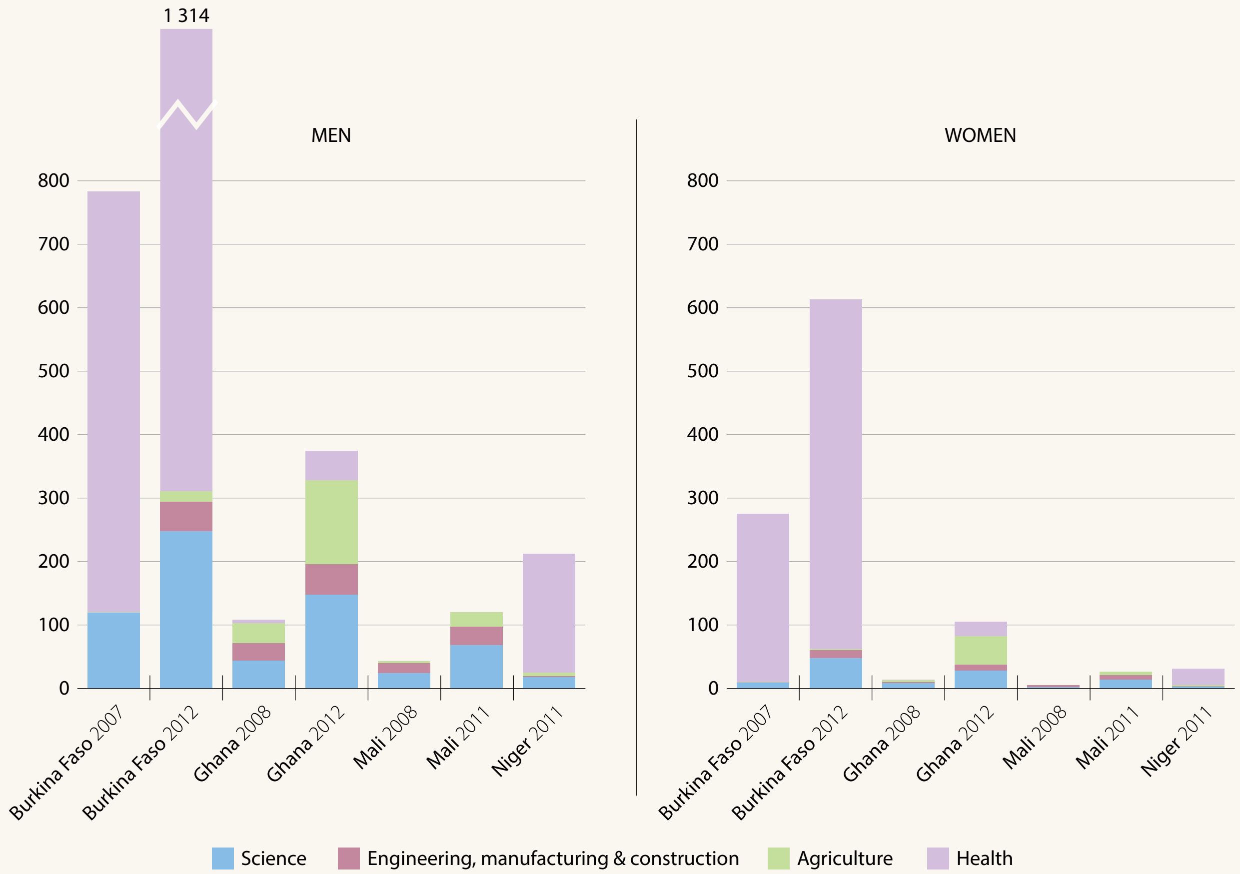
By level and field of study, selected countries

	Total			Science			Engineering, manufacturing and construction			Agriculture			Health		
	Post-secondary	1st & 2nd degree	PhD	Post-secondary	1st & 2nd degree	PhD	Post-secondary	1st & 2nd degree	PhD	Post-secondary	1st & 2nd degree	PhD	Post-secondary	1st & 2nd degree	PhD
Burkina Faso, 2007	7 964	24 259	1 236	735	3 693	128	284	–	0	100	219	2	203	1 892	928
Burkina Faso, 2012	16 801	49 688	2 405	1 307	8 730	296	2 119	303	58	50	67	17	0	2 147	1 554
Côte d'Ivoire, 2012	57 541	23 008	269		12 946			7 817			1 039			1724	
Ghana, 2008	64 993	124 999	281	6 534	18 356	52	7 290	9 091	29	263	6 794	32	946	4 744	6
Ghana, 2012	89 734	204 743	867	3 281	24 072	176	8 306	14 183	57	1 001	7 424	132	3 830	10 144	69
Mali, 2009	10 937	65 603	127	88	6 512	69	0	950	9	602	408	2	1 214	5 202	4
Mali, 2011	10 541	76 769	343	25	1 458	82	137	1 550	36	662	0	23	2 024	3 956	0
Niger, 2009	3 252	12 429	311	258	1 327	30	–	–	–	–	315	4	871	1 814	–
Niger, 2011	3 365	14 678	285	139	1 825	21	240	56	1	0	479	6	1 330	2 072	213

Source: UNESCO Institute for Statistics, January 2015

Figure 18.3: **West African PhD students enrolled in S&T fields by gender, 2007 and 2012 or closest year**

Selected countries



Source: UNESCO Institute for Statistics, January 2015

TRENDS IN R&D

Most countries still far from 1% target

ECOWAS countries still have a long way to go to reach the AU's target of devoting 1% of GDP to GERD. Mali comes closest (0.66%), followed by Senegal (Figure 18.4). The strong economic growth experienced by the subregion in recent years does, of course, make it harder to improve the GERD/GDP ratio, since GDP keeps rising. Although the government is the main source of GERD, foreign sources contribute a sizeable chunk in Ghana (31%), Senegal (41%) and Burkina Faso (60%). Gambia receives nearly half of its GERD from private non-profit sources (see Table 19.5).

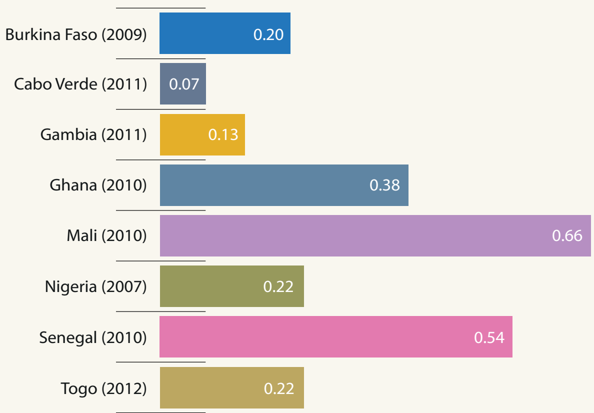
GERD tends to be spent mainly in either the government or university sectors, depending on the country, although only Ghana and Senegal have provided data for all four performing sectors. These data reveal that the share of GERD performed by the business enterprise sector in these two countries is negligible (Figure 18.5). This will need to change if the region is to raise its investment in R&D.

A lack of researchers, in general, and women, in particular

It would be hazardous to extrapolate to the entire subregion without recent data for more than seven countries but the available data do suggest a shortage of qualified personnel. Only Senegal stands out, with 361 full-time equivalent (FTE) researchers per million population in 2010 (Table 18.5). Despite policies promoting gender equality, women's participation in R&D remains low. Cabo Verde, Senegal and Nigeria have some of the best ratios: around one in three (Cabo Verde) and one in four researchers. Concerning the sector of employment, the surprise comes from Mali, where half (49%) of researchers were working in the business enterprise sector in 2010 (Table 18.5).

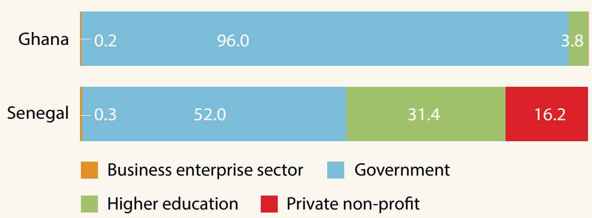
Figure 18.4: **GERD/GDP ratio in West Africa, 2011 or closest year (%)**

Selected countries



Source: UNESCO Institute for Statistics, January 2015

Figure 18.5: **GERD in Ghana and Senegal by sector of performance, 2010**



Note: Complete data for each sector are unavailable for other West African countries.

Source: UNESCO Institute for Statistics, January 2015

Table 18.5: **Researchers (FTE) in West Africa, 2012 or closest year**

	Total			By sector of employment (% of total)			By field of science and share of women											
	Numbers	Per million population	Women (%)	Business sector (%)	Government (%)	Higher education (%)	Natural Sciences	Women (%)	Engineering	Women (%)	Med. & Health Sciences	Women (%)	Agricultural Sciences	Women (%)	Social Sciences	Women (%)	Humanities	Women (%)
Burkina Faso, 2010	742	48	21.6	–	–	–	98	12.2	121	12.8	344	27.4	64	13.7	26	15.5	49	30.4
Cabo Verde, 2011	25	51	36.0	0.0	100.0	0.0	5	60.0	8	12.5	0.0	–	0.0	–	6	50.0	6	33.3
Ghana, 2010	941	39	17.3	1.0	38.3	59.9	164	17.5	120	7.7	135	19.3	183	14.1	197	18.6	118	26.8
Mali, 2010	443	32	14.1	49.0	34.0	16.9	–	–	–	–	–	–	–	–	–	–	–	–
Nigeria, 2007	5 677	39	23.4	0.0	19.6	80.4	–	–	–	–	–	–	–	–	–	–	–	–
Senegal, 2010	4 679	361	24.8	0.1	4.1	95.0	841	16.9	99	14.1	898	31.7	110	27.9	2 326	27.2	296	17.1
Togo, 2012	242	36	9.4	–	22.1	77.9	32	7.1	13	7.8	40	8.3	63	3.8	5	14.1	88	14.1

Note: The sum of the breakdown by field of science may not correspond to the total because of fields not elsewhere classified.

Source: UNESCO Institute for Statistics, January 2015

A modest publication record, little intraregional collaboration

When it comes to scientific publications, West Africa has not progressed as quickly as the rest of the continent since 2005 (Figure 18.6). Output remains low, with only Gambia and Cabo Verde publishing more than 30 articles per million population. In the coming years, the country to watch may be Ghana, where the number of articles almost tripled to 579 between 2005 and 2014.

From 2008 to 2014, the top three partners for ECOWAS authors came from the USA, France and the UK, in that order. South Africa, Burkina Faso and Senegal are the main African partners of ECOWAS countries. In recent years, South Africa has established bilateral agreements with Ghana, Mali and Nigeria to boost co-operation in science and technology (see Table 17.6).

A report by the African Observatory of Science, Technology and Innovation on scientific production in the African Union between 2005 and 2010 indicates that only 4.1% of scientific papers published by Africans involved co-authors from the same continent in 2005–2007 and 4.3% in 2008–2010 (AOSTI, 2014).

Judging from the publication record, ECOWAS research focuses on medical and biological sciences, even if Nigeria did publish 1 250 research articles on agriculture between 2008 and 2014. Agricultural research takes a back seat in most ECOWAS countries, despite being a priority. This is hardly surprising, given the small number of PhDs in agriculture emerging from the universities of most West African countries and the generally low level of investment in agriculture. Research in mathematics, astronomy and computer science is negligible, even among the subregion's leaders, Nigeria and Ghana (Figure 18.6).

In the great majority of ECOWAS countries, more than eight out of ten scientific articles catalogued in the Web of Science between 2008 and 2014 had foreign partners. In the case of Cabo Verde, Guinea-Bissau and Liberia, this was even the case for the totality of articles, although it must be said that these three countries have a low output. There are two exceptions to the rule: in Côte d'Ivoire, three-quarters of articles (73%) had foreign co-authors between 2008 and 2014 and, in Nigeria, just over one-third (37%). In comparison, the average for members of the Organisation for Economic Co-operation and Development (OECD) is 29%. As for G20 countries, they publish just under 25% of articles with foreign partners on average. The average for sub-Saharan Africa is 63%.

COUNTRY PROFILES

BENIN

A need to match R&D with development needs

In Benin, the Ministry of Higher Education and Scientific Research is responsible for implementing science policy. The National Directorate of Scientific and Technological Research handles planning and co-ordination, whereas the National Council for Scientific and Technical Research and National Academy of Sciences, Arts and Letters each play an advisory role.

Financial support comes from Benin's National Fund for Scientific Research and Technological Innovation. The Benin Agency for the Promotion of Research Results and Technological Innovation carries out technology transfer through the development and dissemination of research results.

The regulatory framework has evolved since 2006 when the country's first science policy was prepared. This has since been updated and complemented by new texts on science and innovation (the year of adoption is between brackets):

- A manual for monitoring and evaluating research structures and organizations (2013);
- A manual on how to select research programmes and projects and apply to the National Fund for Scientific Research and Technological Innovation (2013) for competitive grants;
- A draft act for funding scientific research and innovation and a draft code of ethics for scientific research and innovation were both submitted to the Supreme Court in 2014;
- A strategic plan for scientific research and innovation (under development in 2015).

Equally important are Benin's efforts to integrate science into existing policy documents:

- *Benin Development Strategies 2025: Benin 2025 Alafia* (2000);
- *Growth Strategies for Poverty Reduction 2011–2016* (2011);
- Phase 3 of the *Ten-year Development Plan for the Education Sector*, covering 2013–2015;
- *Development Plan for Higher Education and Scientific Research 2013–2017* (2014).

The priority areas for scientific research are health, education, construction and building materials, transportation and trade, culture, tourism and handicrafts, cotton/textiles, food, energy and climate change.

The main research structures are the Centre for Scientific and Technical Research, National Institute of Agricultural Research, National Institute for Training and Research in Education, Office of Geological and Mining Research and the Centre for Entomological Research. The University of Abomey-Calavi also deserves mention for having been selected by the World Bank as a centre of excellence in applied mathematics (Table 18.1).

The main challenges facing R&D in Benin are the:

- unfavourable organizational framework for R&D: weak governance, a lack of co-operation between research structures and the absence of an official document on the status of researchers;
- inadequate use of human resources and the lack of any motivational policy for researchers; and the
- mismatch between R&D and development needs.

BURKINA FASO

S&T have become a development priority

Since 2011, Burkina Faso has clearly made S&T a development priority. The first sign was the creation of the Ministry of Scientific Research and Innovation in January 2011. Up until then, management of STI had fallen under the Department of Secondary and Higher Education and Scientific Research. Within this ministry, the Directorate General for Research and Sector Statistics is responsible for planning. A separate body, the Directorate General of Scientific Research, Technology and Innovation, co-ordinates research. This is a departure from the pattern in many other West African countries where a single body fulfils both functions.

In 2012, Burkina Faso adopted a *National Policy for Scientific and Technical Research*, the strategic objectives of which are to develop R&D and the application and commercialization of research results. The policy also makes provisions for strengthening the ministry's strategic and operational capacities.

One of the key priorities is to improve food security and self-sufficiency by boosting capacity in agricultural and environmental sciences. The creation of a centre of excellence at the International Institute of Water and Environmental Engineering (2iE) in Ouagadougou within a World Bank project (Table 18.1) provides essential funding for capacity-building in these priority areas. Burkina Faso also hosts the African Biosafety Network of Expertise (Box 18.1).

A dual priority is to promote innovative, effective and accessible health systems; the growing number of doctoral candidates in medicine and related fields is a step in the right direction (Figure 18.3). The government wishes to develop, in parallel, applied sciences and technology and social and human sciences. To complement the national research policy, the government has prepared a *National Strategy to Popularize Technologies, Inventions and Innovations* (2012) and a *National Innovation Strategy* (2014).

Other policies also incorporate science and technology, such as that on *Secondary and Higher Education and Scientific Research* (2010), the *National Policy on Food and Nutrition Security* (2014) and the National Programme for the Rural Sector (2011).

In 2013, Burkina Faso passed the Science, Technology and Innovation Act establishing three mechanisms for financing research and innovation, a clear indication of high-level commitment. These mechanisms are the National Fund for Education and Research, the National Fund for Research and Innovation for Development and the Forum of Scientific Research and Technological Innovation[7]. The creation of national funds for R&D is one of the recommendations of ECOPOST.

The other most important actors are the National Centre for Scientific and Technological Research, Institute for Environment and Agricultural Research, National Agency for Biodiversity, National Council for Phytogenetic Resources Management and the Technical Secretariat for Atomic Energy. Responsibility for technology transfer and the popularization of research results falls to the National Agency for the Promotion of Research Results and the National Centre for Scientific and Technological Research.

Burkina Faso faces a number of challenges in developing R&D:

- a small pool of researchers: 48 per million population in 2010;
- a lack of research funding,
- outdated research facilities,
- poor access to information and internet: 4.4% of the population in 2013;
- an insufficient utilization of research results; and
- brain drain.

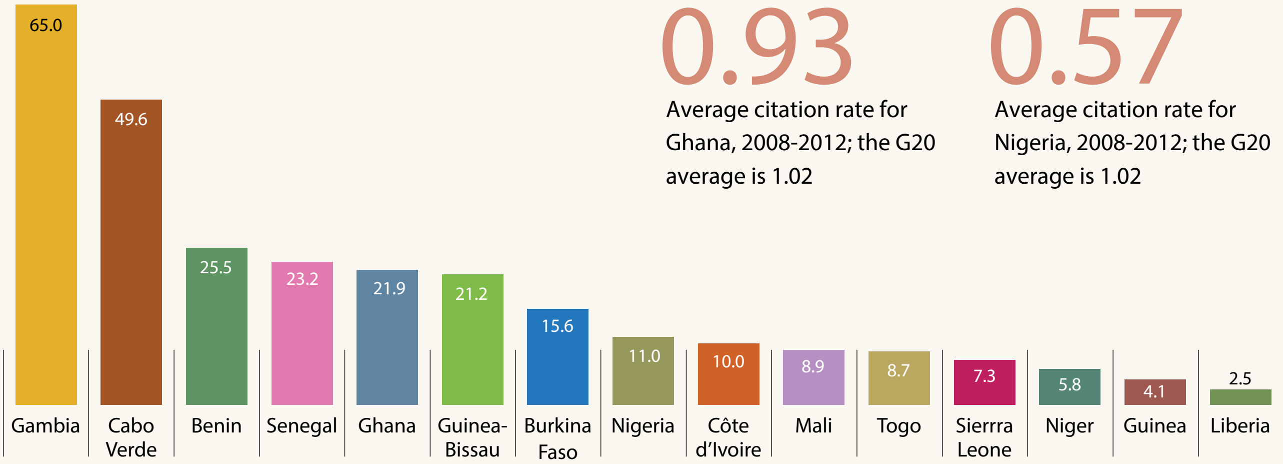
Before he passed away in December 2013, Nelson Mandela, a champion of education, lent his name to two graduate universities entrusted with the mission of producing a new generation of Africa-focused researchers, the African Institutes of Science and Technology in Tanzania and Nigeria. A third is planned for Burkina Faso.

7. Funding comes from the national budget and various annual subsidies: 0.2% of tax revenue, 1% of mining revenue and 1% of the revenue from operating mobile phone licenses. The funds also benefit from royalties on sales from the results of research and the patent license agreement concerning inventions funded by the public purse.

Figure 18.6: **Scientific publication trends in West Africa, 2005–2014**

Scientists from Gambia and Cabo Verde publish most in international journals

Per million inhabitants, 2014



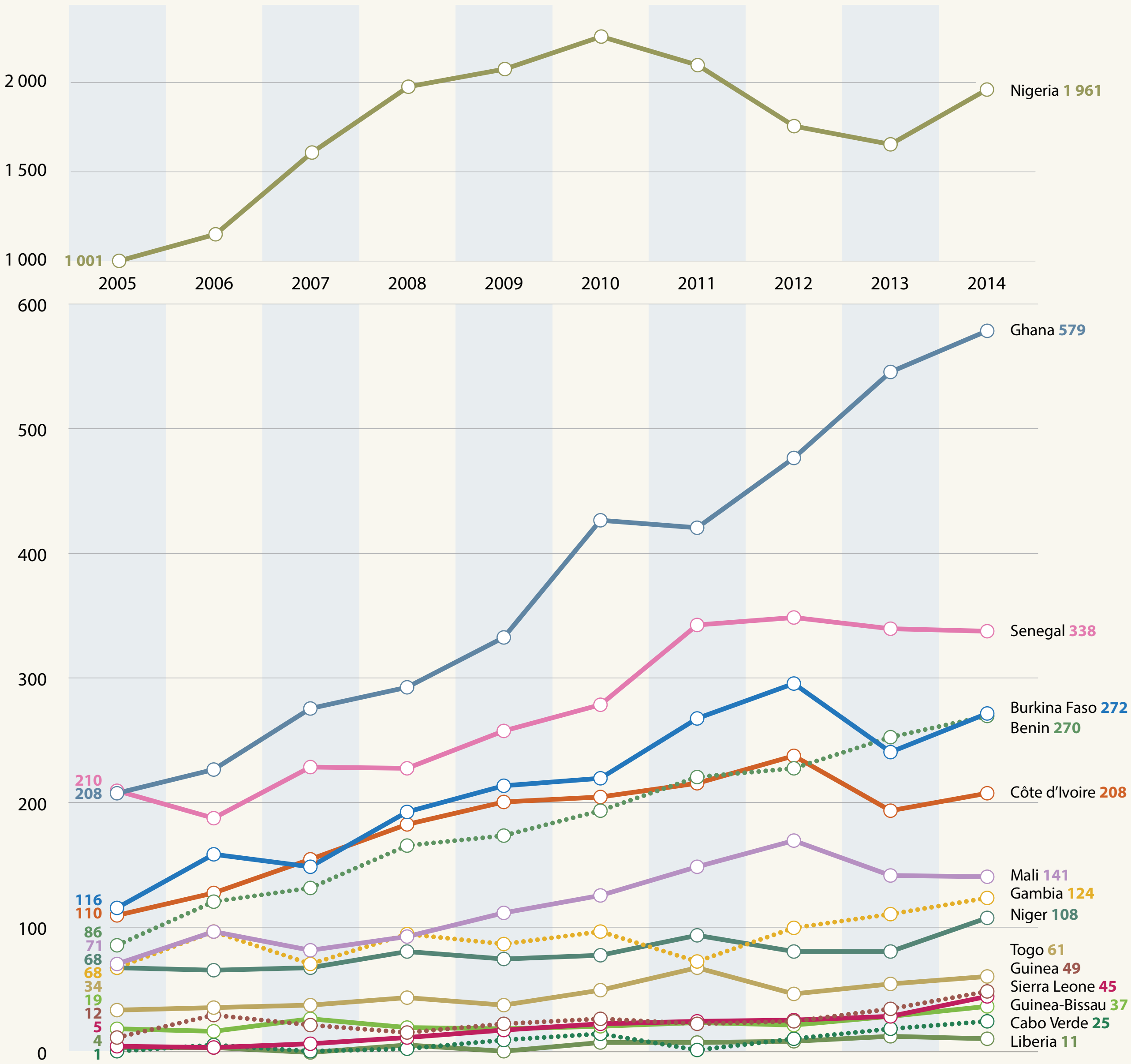
0.93

Average citation rate for Ghana, 2008-2012; the G20 average is 1.02

0.57

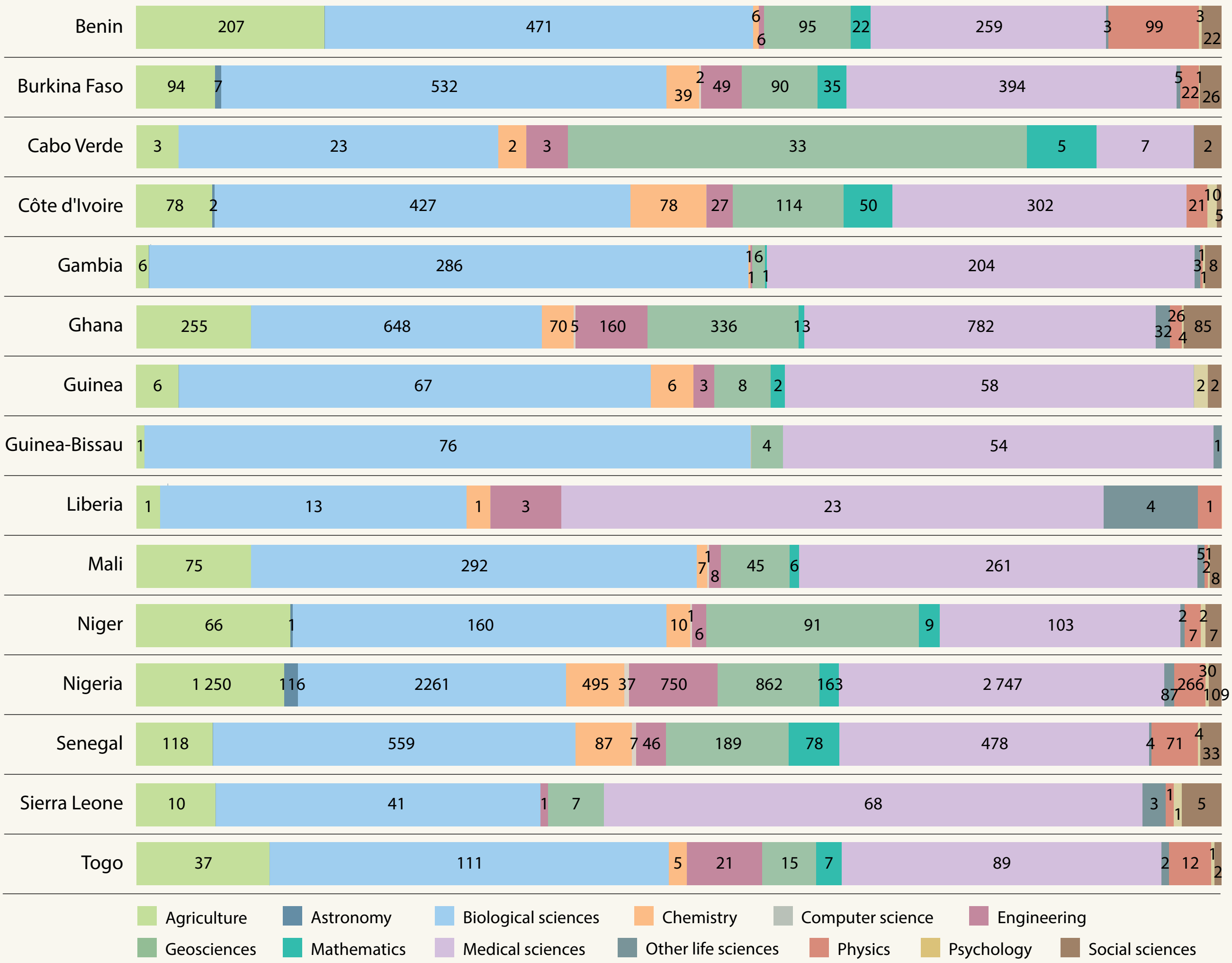
Average citation rate for Nigeria, 2008-2012; the G20 average is 1.02

Ghana now has the second-biggest volume of output after Nigeria



West African scientists publish much more in health than in agriculture

Cumulative totals by field, 2008–2014



Note: Totals exclude unclassified articles.

A wide range of scientific partners, including in Africa

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Benin	France (529)	Belgium (206)	USA (155)	UK (133)	Netherlands (125)
Burkina Faso	France (676)	USA (261)	UK (254)	Belgium (198)	Germany (156)
Cabo Verde	Portugal (42)	Spain (23)	UK (15)	USA (11)	Germany (8)
Côte d'Ivoire	France (610)	USA (183)	Switzerland (162)	UK (109)	Burkina Faso (93)
Gambia	UK (473)	USA (216)	Belgium (92)	Netherlands (69)	Kenya (67)
Ghana	USA (830)	UK (636)	Germany (291)	South Africa (260)	Netherlands (256)
Guinea	France (71)	UK (38)	USA (31)	China (27)	Senegal (26)
Guinea-Bissau	Denmark (112)	Sweden (50)	Gambia /UK (40)	–	USA (24)
Liberia	USA (36)	UK (12)	France (11)	Ghana (6)	Canada (5)
Mali	USA (358)	France (281)	UK (155)	Burkina Faso (120)	Senegal (97)
Niger	France (238)	USA (145)	Nigeria (82)	UK (77)	Senegal (71)
Nigeria	USA (1309)	South Africa (953)	UK (914)	Germany (434)	China (329)
Senegal	France (1009)	USA (403)	UK (186)	Burkina Faso (154)	Belgium (139)
Sierra Leone	USA (87)	UK (41)	Nigeria (20)	China/Germany (16)	–
Togo	France (146)	Benin (57)	USA (50)	Burkina Faso (47)	Côte d'Ivoire (31)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix, November 2014

CABO VERDE

A model for civil rights and development

Cabo Verde remains a model for political rights and civil liberties in Africa, according to a country study by the African Development Bank in 2014. Thanks to its sustained economic performance, this isolated and fragmented territory with a dry Sahelian climate and scarce natural resources acceded to the World Bank's middle-income category in 2011. In order to maintain the momentum, the government has devised its third *Growth and Poverty Strategy Paper* covering the period 2012–2016. Expanding the coverage of health service delivery and human capital development have been designated priority areas, in order to ensure inclusive growth, with an emphasis on technical and vocational training. In recent years, Cabo Verde has invested more than 5% of GDP in education. This strategy has paid off. The literacy rate is now the highest in West Africa (98%), with 93% of young people being enrolled in secondary school and one in five in tertiary education (Table 18.3).

Plans to strengthen research

Research spending, on the other hand, remains among the lowest in West Africa, at 0.07% of GDP in 2011. The Ministry of Higher Education, Science and Culture plans to strengthen the research and academic sectors by placing emphasis on greater mobility, through exchange programmes and international co-operation agreements. As part of this strategy, Cabo Verde is participating in the Ibero-American academic mobility programme that expects to mobilize 200 000 academics between 2015 and 2020.

ICTs at the heart of development plans

Cabo Verde Telecom linked all the islands by fibre optic cable in 2000. In December 2010, it joined the West African Cable System project[8] to provide residents with an alternative access route to high-speed internet. Thanks to this, internet penetration more than doubled between 2008 and 2013 to 37.5% of the population. As the cost remains high, the government provides centres where people can surf the internet free of charge.

The government now plans to build a 'cyber-island' which would develop and offer ICT services, including software development, computer maintenance and back office operations. Approved in 2013, the Praia Technology Park is a step in this direction; financed by the African Development Bank, it is expected to be operational by 2018.

The government launched the Mundu Novu project in 2009 to modernize education. The project is introducing the concept of interactive education into teaching and mainstreaming informatics into curricula at different levels. Some 150 000 computers are being distributed[9] to public schools. By early 2015, the Mundu Novu education plan had equipped 18 schools and training centres with internet access, installed the Wimax antenna network across the country, produced teaching kits on ICTs for 433 classrooms in 29 pilot schools (94% of all classrooms), given university students access to digital libraries and introduced courses in information technology, in addition to implementing an Integrated Management and Monitoring System for university students.

8. See: www.fosigrid.org/africa/cape-verde

CÔTE D'IVOIRE

A plan to consolidate peace and promote inclusive growth

With the political crisis now over, the incoming government of President Alassane Ouattara has vowed to restore the country to its former leading role in sub-Saharan Africa. The *National Development Plan for 2012–2015* has two primary objectives: to achieve double-digit growth by 2014 and to turn Côte d'Ivoire into an upper middle-income country by 2020. A second national development plan is under preparation for 2016–2020.

The budget for the *National Development Plan* is broken down into five strategic areas: greater wealth creation and social equity (63.8%, see Figure 18.7), provision of quality social services for vulnerable populations, particularly women and children (14.6%), good governance and the restoration of peace and security (9.6%), a healthy environment (9.4%) and the repositioning of Côte d'Ivoire on the regional and international scenes (1.8%).

Key targets of the *Plan* requiring recourse to S&T include:

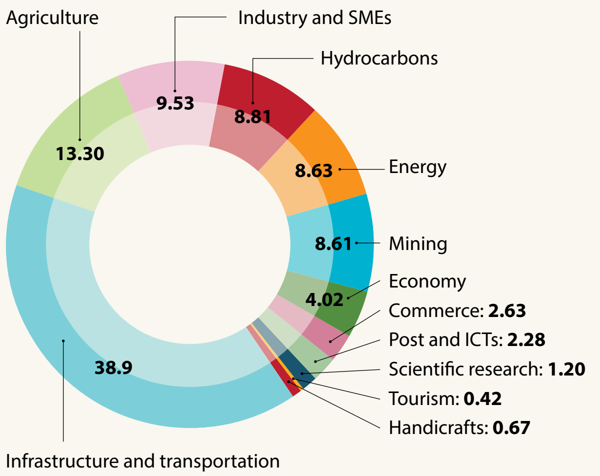
- rehabilitation of the railway linking Abidjan to Burkina Faso's border, rehabilitation and extension of the ports of Abidjan and San Pédro, creation of a new airline company (infrastructure and transport);
- increasing the productivity of yam, banana plantain and manioc by at least 15% (agriculture);
- creation of two transformation units for iron and manganese and one for gold refining (mining);
- construction of the Soubré dam, electrification of 200 rural communities each year (energy);
- establishment and equipping of three technopoles to promote innovation, transformation of 50% of raw materials into value-added goods (industry and SMEs);

9. Microsoft has given the official government agency working on Mundu Novu, Operational Information Society Nucleus, a 90% discount on the operating systems being installed in schools, through an agreement signed in August 2010.

- expansion of the country's fibre optic[10] network, introduction of an e-education programme, establishment of cybercentres in every municipality (post and ICTs);
- construction and equipping of 25 000 classrooms, construction of four universities and a university village, rehabilitation of several existing universities (education);
- rehabilitation of hospitals and clinics, free health care for children under the age of five, free childbirth care and free emergency care (health);
- construction of latrines in rural areas, rehabilitation of sewage systems in Abidjan and Yamoussoukro (sanitation);
- connection of 30 000 low-income families each year to subsidized piped water (drinking water);
- rehabilitation of the lagoon and Cocody Bay in Abidjan and construction of a technopole to treat and recycle industrial and dangerous waste (environment).

Figure 18.7: **Priority sectors of Côte d'Ivoire's *National Development Plan* to 2015**

Within budget devoted to greater wealth creation and social equity (%)



Source: Ministry of Planning and Development (2012) *National Development Plan, 2012–2015*

Infrastructure is a top priority

The share of the *Plan* devoted to scientific research remains modest (Figure 18.7). Twenty-four national research programmes group public and private research and training institutions around a common research theme. These programmes correspond to eight priority sectors for 2012–2015, namely: health, raw materials, agriculture, culture, environment, governance, mining and energy; and technology.

According to the Ministry of Higher Education and Research, Côte d'Ivoire devotes about 0.13% of GDP to GERD.

10. Just 2.4% of Ivorians had internet access in 2012.

Apart from low investment, other challenges include inadequate scientific equipment, the fragmentation of research organizations and a failure to exploit and protect research results.

Côte d'Ivoire does not yet have a dedicated STI policy. Related policies are implemented by the Ministry of Higher Education and Scientific Research. The main planning body is the Directorate General of Scientific Research and Technological Innovation and its technical directorate. For its part, the Higher Council for Scientific Research and Technological Development serves as a forum for consultation and dialogue with stakeholders and research partners.

Research and innovation are promoted and funded by the National Agricultural Investment Programme (est. 2010), the Policy Support Programme for Scientific Research (est. 2007), the Interprofessional Fund for Agricultural Research and Advice (est. 2002), the National Fund for Scientific and Technological Research (yet to be established) and the Ivorian Fund for the Development of National Enterprises (est. 1999).

The following structures foster innovation and technology transfer: the Department for the Promotion of Research and Technological Innovation, the Ivorian Organization for Intellectual Property and Promotion and the Centre for the Demonstration of Technologies. To this list should be added the Ivorian Society of Tropical Technology. Set up in 1979, this government centre promotes agro-industrial innovation and provides training in the preservation and transformation of crops (manioc, banana plantain, cashew nut, coconut, etc.) into value-added goods such as soap and cocoa butter.

Other key structures include the Pasteur Institute, Centre for Oceanological Research, National Centre for Agronomic Research, National Institute of Public Health, Centre for Ecological Research and the Centre for Economic and Social Research.

GAMBIA

A desire to link training with STI development

Gambia's *Programme for Accelerated Growth and Employment,* covering the period 2012–2015, drives its own vision of attaining middle-income status. One of the smallest countries in West Africa, with a per capita GDP of PPP$ 1 666, Gambia is conscious of the need for a robust STI capacity to address its pressing development challenges. Just 14% of the population has access to internet, for instance, and only three in four Gambians have access to a clean water supply.

The establishment of the Ministry of Higher Education, Research, Science and Technology in 2007 signals the country's desire to link the training of skilled personnel with STI development. Other encouraging signs are the president's decision to make 2012 the Year of Science, Technology and Innovation, the efforts to establish the first-ever national academy of sciences in Gambia and the adoption of the *National Science, Technology and Innovation Policy 2013–2022,* prepared with UNESCO's assistance.

This policy aims specifically to foster entrepreneurship among youth and women, in order to enhance their employability. It also aims to modernize both agriculture (peanuts and derivatives, fish, cotton lint, palm kernels) and national industries (tourism, beverages, agricultural machinery assembly, woodworking, metalworking, clothing) to create quality products and services.

A number of institutions provide research and training, the main ones being the University of Gambia, the National Agricultural Research Institute, the Centre for Innovation against Malaria, the Public Health Research and Development Centre, the Medical Research Council and the International Trypanotolerance Centre.

Low tertiary enrolment, little R&D

Development indicators for Gambia are fairly encouraging for a small country with limited resources. Public expenditure on education has quadrupled since 2004 to 4.1% of GDP. Of this, just 7% (0.3% of GDP) is invested in tertiary education. Although nine out of ten children attend primary school, enrolment rates have not progressed at either the primary or secondary levels since 2009, suggesting that the government may be focusing on improving the quality of primary and secondary education (Table 18.3). Tertiary enrolment remains extremely low, at just 3% of the 18–25 age cohort, even though it has risen in recent years.

Just 0.13% of GDP is spent on R&D (2011). Gambia does have the particularity, though, of having an active private non-profit sector, which performs nearly half of R&D[11] according to available data – although it should be noted that the business enterprise sector has not been surveyed. On the whole, however, STI in Gambia is characterized by inadequate infrastructure and insufficient skills and institutional capacity to realize its science and innovation goals, combined with a lack of funding. The *National Science, Technology and Innovation Policy* is intended to address these constraints.

11. This may be at least partly due to the fact that the Medical Research Council in Gambia, a unit of the UK's council of the same name, is classified as a private non-profit institution.

GHANA

A desire to create a science culture

The *Ghana Shared Growth and Development Agenda 2014–2017* contextualizes the sector-specific policies for agriculture, industry, health and education defined by the *National Science, Technology and Innovation Policy*[12] (2010). The main objectives of this policy are to use STI to reduce poverty, increase the international competitiveness of enterprises and promote sustainable environmental management and industrial growth. The long-term goals of the policy are to create a science and technology culture oriented towards problem-solving.

Ghana has one of West Africa's most developed national innovation systems. There is a Council for Scientific and Industrial Research, established in 1958, with 13 specialized institutes for research on crops, animals, food, water and industry. The export of cocoa contributed over 40% of the country's foreign exchange earnings up until the 1980s and still contributes about 20%. The Cocoa Research Institute of Ghana plays an important role in developing the cocoa industry, through research into crop breeding, agronomy, pest management and extension services, among others. Other scientific institutions include the Ghana Atomic Energy Commission, the Centre for Scientific Research into Plant Medicine and the Noguchi Memorial Institute for Medical Research at the University of Ghana.

Ghana has only a small pool of researchers (39 per million population in 2010) but they are increasingly publishing in international journals. Ghana's scientific publication record almost tripled between 2005 and 2014 (Figure 18.6). This performance is all the more noteworthy in that Ghana devoted just 0.38% of GDP to GERD in 2010 (see Table 19.5).

Greater investment needed to stimulate R&D

Between 2004 and 2011, Ghana invested 6.3% of GDP in education, on average, and between one-fifth and one-quarter of this in higher education. The number of students enrolled in degree courses shot up from 82 000 to 205 000 (12% of the age cohort) between 2006 and 2012 and the number of PhD candidates from 123 to 867 (see Table 19.4).

The investment in education has not lived up to expectations, as it has not acted as a stimulus for R&D. This is because science and engineering are accorded insufficient status in Ghana. Government scientists and academics (who perform 96% of GERD) receive an inadequate budget and private sector opportunities are rare. In the 2000s, successive governments made efforts to enhance the infrastructure for modern business

12. This policy followed a review of Ghana's national innovation system by UNCTAD, the World Bank and Ghana's Science and Technology Policy Research Institute.

development. They fostered business incubators for ICTs, industrial parks for textiles and garments and smaller experimental incubators within research institutes like the Food Research Institute. These are all located in the Accra-Tema metropolis where they are too inaccessible for the thousands of entrepreneurs living outside the capital who need these facilities to develop their businesses.

Despite insufficient investment, some universities maintain high standards, such as the University of Ghana (1948), the country's oldest, and Kwame Nkrumah University of Science and Technology (KNUST, 1951). Both have been selected for the World Bank's African Centres of Excellence project (Table 18.1). KNUST has developed a reputation for excellence in engineering, medicine, pharmacy, basic sciences and applied sciences. In 2014, the government established a centre of excellence in petroleum engineering at KNUST with the World Bank which will serve as a hub for developing Africa's capacity in the oil and gas value chain. In all, seven public universities conduct extensive R&D.[13]

Within the World Bank project, the West Africa Centre for Crop Improvement at the University of Ghana is receiving US$ 8 million for research and the training of crop breeders at PhD and MSc levels over 2014–2019, as well as for the provision of other services. The West Africa Centre on the Cell Biology of Infectious Pathogens within the University of Ghana and KNUST's Regional Water and Environmental Sanitation Centre are receiving similar support (Table 18.1).

GUINEA

Middle-income status by 2035

Following the death of President Lansana Conte in 2008, Guinea experienced a severe political crisis until the election of the current President Alpha Conde in November 2010. This challenging political transition plunged the country into an economic recession in 2009 (-0.3% growth), prompting the government to extend its *Poverty Reduction Strategy* to 2012.

The ambition of the new authorities is to transform Guinea into a middle-income economy within 25 years. This ambition will be articulated in *Guinea 2035*, which was under preparation in 2015. The government intends to promote:

- the collection of economic intelligence, in order to anticipate changes in the national and international economic environments and to identify opportunities for access to new markets through innovation and creativity. Over the period 2013–2015, economic intelligence poles are being established for the administration (public services) and private sector (employers);
- clean industries;
- security of intellectual and economic property;
- management and exploitation of knowledge and information, in the priority areas of science and industrial, technological and medical production processes.

Key reforms in higher education and research

The government has made it a priority to achieve universal primary education by 2015, in line with the Millennium Development Goals. The roadmap for achieving this ambition is the government's *Programme for the Education Sector 2008–2015*, adopted in 2007. By 2009, 85% of children were attending primary school but this share had barely progressed by 2012, no doubt owing to the political unrest in 2008 and 2009. The share of secondary pupils rose from 34% to 38% between 2008 and 2012 (Table 18.3). Guinea's education effort accounted for 2.5% of GDP in 2012, one of the lowest proportions in West Africa.

One-third of education expenditure goes on higher education. One in 10 Guineans aged between 18 and 25 years is enrolled at university, one of the highest rates in West Africa. Important reforms are under way in Guinea to improve university governance and the financing of institutions of higher learning and scientific research, to create an advanced (doctoral) graduate school, implement a system of quality assurance and develop relevant professional networks in higher education.

The government is also promoting access to ICTs and their use in teaching, scientific research and administration. Guinea currently has one of the lowest rates of internet penetration in Africa, at just 1.5% (2012).

A need to review the legal framework for R&D

The development of R&D is governed by the Guidance Law for Scientific and Technical Research. This law has not been updated since its adoption on 4 July 2005, nor implemented or reviewed.

The Ministry of Higher Education and Scientific Research is the main body responsible for policies related to higher education and scientific research. Within the ministry, the National Directorate for Scientific and Technical Research (DNRST) is responsible for the implementation of the policy and research institutions that constitute the executive component. The DNRST is also responsible for designing, developing and co-ordinating the monitoring and evaluation of national policy.

13. In addition, there are ten polytechnics, one in each of Ghana's ten administrative regions and 23 institutes for vocational and technical training. The evolving policy on polytechnics is to transform these into technical universities.

In addition to the Ministry of Higher Education and Scientific Research, there is a Higher Council of Scientific and Technical Research. This consultative body related to on matters has national S&T policy; it consists of representatives of ministries, the scientific community and users of the products of research.

R&D funding comes from two sources: the state, through the national development budget, allocates grants to research institutions, documentation centres and universities; and international co-operation. In recent years, R&D in Guinea has received financial assistance from France, via its Aid Fund for Co-operation and the Priority Solidarity Fund, as well as from Japan, Belgium, Canada, the World Bank, UNDP, UNESCO, the Islamic Educational, Scientific and Cultural Organization and others.

GUINEA-BISSAU

Political troubles have undermined the economy

Once hailed as a model for African development, Guinea-Bissau has suffered a civil war (1998–1999), followed by several coups d'état, the latest in April 2012. Political instability has undermined the economy, making it one of the poorest countries in the world.

Guinea-Bissau is dependent on primary crops – mainly cashew nuts for its foreign exchange – and subsistence agriculture. There are other resources that could be exploited and processed, such as fish, timber, phosphates, bauxite, clay, granite, limestone and petroleum deposits.

Guinea-Bissau's long-term vision is encapsulated in *Guinea-Bissau 2025 Djitu ten* (1996). The government's vision is articulated in the first *National Strategy for Poverty Reduction* covering the period 2008–2010 and its successor covering 2011–2015. The title of the latter reflects the strategy's overarching goals, *Reducing Poverty by Strengthening the State, Accelerating Growth and Achieving the Millennium Development Goals*.

Higher education policy currently under review

Like most WAEMU countries which share a common currency (the CFA), Guinea-Bissau has made considerable efforts in the past five years to improve its higher education system. These efforts have been supported by Guinea-Bissau's partners and especially by WAEMU through its Support to Higher Education, Science and Technology Project and its assistance in developing Guinea-Bissau's higher education policy in 2011. This policy is currently under review, in consultation with key stakeholders, particularly private-sector employers, socio-professional organizations, policy-makers and civil society.

Thus, like other WAEMU countries, Guinea-Bissau has held national consultations on the future of higher education and scientific research. In March 2014, the Ministry of Education organized a national dialogue on this topic on the theme of What Future for Higher Education and Scientific Research in Guinea-Bissau in the Short, Medium and Long Term? The consultation brought together a wide range of national and foreign stakeholders. The recommendations emanating from this consultation, combined with the election of President José Mario Vaz in May 2014 and the consequential removal of the sanctions imposed by the African Union after the coup d'état in 2012, should enable Guinea-Bissau to take this reform agenda forward.

LIBERIA

Strong economic growth has not spilled over into the STI sector

Liberia is a country recovering from a quarter of a century of civil war. Although it has turned the page of strife since the election of President Ellen Johnson Sirleaf in 2005, the economy remains in ruins and, since early 2014, has been struggling with the crippling effects of the Ebola epidemic. With GDP per capita of just PPP$ 878 in 2013, Liberia remains one of the poorest countries in Africa.

The country does have considerable natural assets, including the largest rainforest in West Africa. Its economy is based on rubber, timber, cocoa, coffee, iron ore, gold, diamonds, oil and gas. Between 2007 and 2013, the economy grew by 11% on average. Even though this economic recovery is commendable, it has not spilled over into the STI sector.

Low public spending on agriculture and education

Nor has public spending risen in such key sectors as agriculture (less than 5% of GDP) and education (2.38% of GDP), where just 0.10% of GDP goes to higher education. Although Liberia has achieved universal primary education, less than half of pupils attend secondary school. In addition, university enrolment has stagnated: almost the exact same number of students (33 000) were enrolled in degree courses in both 2000 and 2012. At the other extreme, Liberia shares the distinction with Sierra Leone of devoting more of GDP to health (15%) than any other country in sub-Saharan Africa.

An emphasis on better governance

Liberia has set its sights on becoming a middle-income country by 2030, in its *National Vision: Liberia Rising 2030*[14] (Republic of Liberia, 2012). The first priority will be to create the conditions for socio-economic growth, through better governance

14. *Liberia Rising* 2030 follows on the heels of *Lifting Liberia*, the country's poverty reduction strategy for 2008–2011.

practices such as respect for the rule of law, infrastructure development, a more business-friendly environment, free basic education and more trained teachers, investment in technical and vocational education and higher education. *Liberia Rising* cites a World Bank Doing Business survey (2012) in which 59% of Liberian firms identified lack of electricity and 39% lack of transportation as a major constraint.

With the entire infrastructure for energy generation and distribution having been destroyed by the war, it is planned to make greater use of renewable energy and to install affordable power services, with 'more access to fuel that does not contribute to deforestation.' Being able to supply electricity to most of the economy is considered 'essential' for achieving middle-income status. Emphasis is being placed on ensuring greater inclusiveness, as 'instability and conflict remain the primary risk to long-term wealth creation in Liberia…The challenge will be to turn away from the traditional practice of concentrating wealth and power in the elite and in Monrovia (the capital).'

It is expected that financing for the *National Vision* will come essentially from large mining companies – including those currently prospecting offshore for oil and gas – and from development partners. In 2012, FDI contributed 78% of GDP, by far the largest share in sub-Saharan Africa (Republic of Liberia, 2012).

Liberia has not yet published an STI policy but it does have a national industrial policy, *Industry for Liberia's Future* (2011), a *National Environmental Protection Policy* (2003), a *National Biosafety Framework* (2004) and a *National Health Policy* (2007).

An S&T college for the University of Liberia

In higher education, the main development has been the commissioning of the T.J.R. Faulkner College of Science and Technology in 2012 at the University of Liberia. The latter was founded in 1862 and already had two colleges, the College of Agriculture and Forestry and the College of Medicine. Other universities also have science and engineering faculties. Liberia also has specialized institutions such as the Liberia Institute for Biomedical Research and the Central Agriculture Research Institute.

The National Commission on Higher Education is responsible for developing STI. There is also a Renewable Energy Agency, a Forestry Development Authority and an Environmental Protection Agency. Currently, the Ministry of Education holds responsibility for science education and research, through its Division for Science and Technology Education. There are calls, however, for the establishment of a Ministry of Research, Science and Technology.

MALI

A policy but no long-term plan for research

In 2009, the Ministry of Secondary and Higher Education and Scientific Research developed a *National Policy for Higher Education and Scientific Research* (MoSHESR, 2009). It has three main objectives:

- to strengthen the social and economic utility of higher education and research;
- to regulate the flow of students enrolled in higher education, in order to establish the best possible compromise between the needs of the labour market, social demand and the available means; and
- to optimize available resources by directing the lion's share towards teaching and research, while making better use of the private sector's potential role, in order to limit social spending.

Despite the guidance offered by this science policy, no strategic plan for developing long-term scientific research has yet been formally adopted, nor any document defining the human, material and financial resources needed to mobilize and implement such a policy. The United Nations' Economic Commission for Africa did support a study in 2009–2011 on developing a national STI policy and an accompanying implementation plan but this process was perturbed by the military coup in 2011 which preceded the Touareg rebellion in the north. In the absence of these elements, departments or individuals within education and research structures continue to initiate research projects themselves or, in some cases, the initiative is taken by donors, an only too familiar pattern in Africa.

From one university to six

Until 2011, Mali had a single university, established in 1996. Nearly 80 000 students enrolled in the 2010–2011 academic year, 343 of whom were PhD candidates (Table 18.4). In order to accommodate the burgeoning student numbers, the government decided to divide the University of Bamako into four separate entities in 2011, each with its own institute of technology: the University of Science, Techniques and Technologies in Bamako; University of Arts and Humanities in Bamako; University of Social Sciences and Management in Bamako; and the University of Law and Political Sciences in Bamako.

In parallel, the University of Segou was approved by decree in 2009 and welcomed its first cohort of 368 students in January 2012, according to the Malian journal *L'Essor*. The Faculty of Agriculture and Veterinary Medicine was the first to open, followed by the Faculty of Social Sciences, the Faculty of Health Sciences and the Faculty of Science and Engineering. It is planned to set up a vocational training centre on campus.

Since 2009, the UNESCO Office in Bamako has been implementing a project to help university professors adopt the three-tier degree cycle (bachelor's– master's –PhD). UNESCO collaborated with the University of Bamako and the National Directorate of Higher Education in organizing a mission to Dakar in April 2013 for about 20 university professors, so that they could study doctoral schools and quality assurance mechanisms in Senegal with a view to emulating these in Mali. UNESCO also ran a number of national and international workshops, including one on the use of ICTs to improve education and research. The University of Bamako has since joined the African Network of Scientific and Technological Institutions, hosted by the UNESCO Nairobi office.

NIGER

The country's first STI policy

In Niger, several ministries are involved in designing S&T policy but the Ministry of Higher Education, Scientific Research and Innovation is the principal player. The *National Policy on Science, Technology and Innovation* was approved in 2013 and was awaiting adoption by parliament in 2015. In parallel, UNESCO is helping Niger develop a strategic implementation plan.

In March 2013, Niger participated in a subregional workshop[15] in Dakar co-organized by UNESCO's Global Observatory of STI Policy Instruments (GO→SPIN) programme and AOSTI. The workshop was the first step in mapping research and innovation in Niger.

In 2010, Niger created a Support Fund for Scientific Research and Technological Innovation (FARSIT). With an annual budget of CFA 360 million (€ 548 000), FARSIT aims to support research projects of socio-economic relevance; strengthen the capacity of institutions, teams and laboratories to conduct R&D; encourage creativity and technological innovation; and improve research training.

A first long-term plan for all levels of education

University enrolment rates in Niger are among the lowest in Africa, at just 175 students per 10 000 population (Table 18.3). Developing a viable higher education system of quality thus remains a major challenge for a country where half the population is less than 15 years of age. In 2010, three new universities were founded: the University of Maradi, the University of Zinder and the University of Tahoua.

In 2014, the government adopted a *Programme for the Education and Training Sector, 2014–2024*.This is Niger's first long-term planning document for education as a whole, from the pre-primary to tertiary levels. The previous plan in 2001 focused solely on basic education, encompassing pre-school, primary school, adult literacy and non-formal education.

NIGERIA

The National Fund for STI approved

Nigeria plans to use its *Vision 20:2020: Economic Transformation Blueprint* (2009) to place it among the top 20 economies[16] in the world by 2020, with annual per capita income of at least US$ 4 000. *Vision 20:2020* integrates STI into the development of key economic sectors and is built on three pillars, namely: optimizing the nation's key sources of economic growth; guaranteeing the productivity and well-being of Nigerians; and fostering sustainable development.

One of the nine strategic targets of *Vision 20:2020* was initially to set up a US$ 5 billion endowment fund to finance the establishment of a National Science Foundation. This fund was pledged by former President Olusegun Obasanjo (1999–2007) towards the end of his mandate and has not materialized. Progress towards other targets is hard to evaluate for lack of data, examples being the target of investing a share of GDP in R&D comparable to that of the 20 leading economies or that of increasing numbers of R&D personnel.

In 2011, the Federal Executive Council approved the allocation of 1% of GDP to set up a National Science, Technology and Innovation Fund. This strategy features in the *Science, Technology and Innovation Policy* approved by the Federal Executive Council in 2011, which recommends putting in place reliable funding arrangements to ensure that R&D focuses on national priorities. Four years later, this fund has not yet materialized.

A policy shift towards innovation

The policy also recommended a shift in research focus from basic research to innovation. In his foreword, the Federal Minister of Science and Technology[17] observed that 'one notable feature of this policy is the emphasis on innovation, which has become a tool for fast-tracking sustainable development.' President Goodluck Jonathan put it this way: 'we are going to run our economy based on S&T because nowhere in this world can you move the economy without S&T…for the next four years, we will emphasize S&T so much

15. The workshop was attended by high-level experts, government officials, researchers, statisticians and parliamentary commission staff from Burkina Faso, Burundi, Côte d'Ivoire, Gabon, Niger and Senegal.

16. For details of Nigeria *20:2020*, see the *UNESCO Science Report 2010: the Current Status of Science around the World*, p. 309.

17. The Federal Ministry of Science and Technology is supported by the National Council on Science and Technology, the National Assembly Committees on Science and Technology and the National Centre for Technology Management. Nigeria being a federal republic, there are also relays in the state ministries and assemblies.

Box 18.4: **Taxing business to upgrade tertiary education in Nigeria**

One of the strategies outlined in Nigeria's *Science, Technology and Innovation Policy* (2011) is for funding frameworks to be set up with various partners.

One such framework is the TETFund. It was established under the Tertiary Education Trust Fund Act of 2011 to serve as the agency responsible for managing and disbursing tax funds to public tertiary institutions. It is also responsible for monitoring the utilization of funds.

Under the fund, a 2% education tax is imposed on the assessable profits of all registered companies in Nigeria. TETFund then disburses 50% of the money to universities, 25% to polytechnics and 25% to teachers' colleges. Grants are provided for the purchase of essential physical infrastructure for teaching and learning, research and publication and academic staff training and development.

Source: www.tetfund.gov.ng

because we have no choice.' The aim is to transform Nigerians into 'science and technology thinking entities.'

The policy also recommended founding a National Research and Innovation Council. This was effectively established in February 2014. Membership includes the federal ministers of science and technology; education; information and communications technology; and environment.

The emphasis in STI is on space science and technology, biotechnology and renewable energy technologies. Although Nigeria has had a National Biotechnology Development Agency since 2001, the National Biosafety Management Agency Bill lingered in parliament for years; the bill was finally passed in 2011 but was still awaiting presidential consent in early 2015.

In 2012, an International Centre for Biotechnology was established under the auspices of UNESCO at the University of Nigeria in Nsukka. The institute provides high-level training (including at subregional level), education and research, particularly in areas related to food security, conservation of harvested crops, gene banking and tropical diseases.

Some key goals of the *Science, Technology and Innovation Policy* are to:

- develop an endogenous capability in launching and exploiting Nigeria's own satellites (it already has three) for telecommunications and research;
- run advanced field trials of genetically modified crops designed to increase agricultural productivity and food security (see also Box 18.1);
- promote solar technology systems as dependable back-ups to the national grid and to address energy needs in marginalized communities;
- promote the design and use of local construction materials and a 'green construction culture' through the development of 'green homes' and 'green cement;'
- establish or develop technology transfer offices to improve intellectual property protection and thereby encourage industrial R&D;
- build the Sheda Science and Technology Complex (SHESTCO) in Abuja within the Silicon Valley Project, which is developing a high-tech capability in ICTs, materials science, solar and new technologies, along with skills in engineering and maintenance. In a visit to the complex in October 2014, the Federal Minister of Science and Technology, Dr Abdu Bulama, pledged to 'do everything under our mandate to ensure Silicon Valley becomes a reality. Hence, we are partnering with UNESCO, Poland and other international bodies to fast-track the process.'

The success of Nigeria's ambitious programme will rest on its strategy for developing human resources (Box 18.4). Nigeria currently has 40 federal universities, 39 state universities and 50 private universities, according to the Nigeria Universities Commission. There are also 66 polytechnics, 52 monotechnics and about 75 research institutes.

Despite this, federal spending on R&D in 2007 represented only about 0.22% of GDP, according to the UNESCO Institute for Statistics, and over 96% of this was provided by the government. These statistics should improve as implementation of the *Science, Technology and Innovation Policy* progresses.

Economic diversification an urgent necessity

The president has implemented two schemes to support the economy since 2010:

- With power outages costing the Nigerian economy billions of dollars each year, the president launched a *Roadmap for Power Sector Reform* in 2010. Central to this scheme has been the privatization of the state electricity provider, the Power Holding Company of Nigeria, which has been broken up into 15 different companies.

- In October 2011, the president launched the Youth Enterprise with Innovation in Nigeria (You Win)[18] grant scheme to generate jobs. By 2015, some 3 600 aspiring entrepreneurs between 18 and 45 years had received up to 10 million naira each (US$ 56 000) to help them launch or expand their business, mitigate start-up risks or set up spin-offs from existing businesses. A fledgling ICT business and dental clinic figure among the recipients.

One of the goals of Vision *20:2020* is to diversify the economy, yet, by 2015, oil and gas still accounted for 35% of Nigeria's economic output and 90% of its exports, according to OPEC. With the Brent crude price having more than halved to about US$ 50 since mid-2014, Nigeria has devalued the naira and announced plans to cut public spending by 6% in 2015. More than ever, economic diversification is an urgent necessity.

SENEGAL

A focus on higher education reform

In 2012, Senegal adopted a *National Strategy for Economic and Social Development for 2013–2017*, based on the vision of its *Senegal Emerging Plan*, Senegal's development plan for becoming an upper middle-income country by 2035. Both documents consider higher education and research as a springboard to socio-economic development and thus a priority for reform.

In early 2013, a national dialogue was held on the future of higher education. It produced 78 recommendations that the Ministry of Higher Education and Research has since translated into an action plan entitled *Priority Programme Reform and the Development Plan for Higher Education and Research, 2013–2017* (PDESR). This action plan was adopted in stages by the Presidential Council on Higher Education and Research through 11 presidential decisions taken by the Head of State, including a funding commitment of US$ 600 million over five years.

In its first year of implementation, PDESR created three new public universities: the University of Sine Saloum of Kaolack in central Senegal, specializing in agriculture, the Second University of Dakar, situated 30 km from Dakar and specializing in basic sciences, and the Virtual University of Senegal. Within the plan, a network of vocational training institutes and upgraded laboratories has been developed with the introduction of high bandwidth to connect public universities with one another.

A lot remains to be done, however. There is little synergy in R&D, which suffers from a low budget and inadequate equipment, a low status for researchers and a lack of university–industry linkages. Research results are also insufficiently applied, owing to weak oversight and relatively low scientific output (Figure 18.6).

New governing bodies and an astronomical observatory

The creation of a National Council of Higher Education, Research, Innovation, Science and Technology in 2015 should allow Senegal to meet some of these challenges. It will act as a consultative committee to the Minister of Higher Education and Research and as a monitoring body. The ongoing construction of Senegal's first planetarium and mini-astronomical observatory could also be a sign of a growing science culture.

A law passed in December 2014 should also help to galvanize research. The law creates a governing board for universities. Half of board members must be external to the university, such as from the private sector.

Another new development has been the creation of the Directorate-General for Research in 2014. Placed under the Ministry of Higher Education and Research, it is responsible for planning and co-ordinating research at the national level, especially that conducted by universities and academic research institutes. The ministry relies on the National Agency for Applied Scientific Research, the National Academy of Science and Technology of Senegal and the Senegalese Agency for Intellectual Property and Technological Innovation to promote Senegalese research.

Some national research institutions fall under the authority of other ministries, such as the Institute for Food Technology (Ministry of Mines and Industry), the Senegalese Institute for Agricultural Research and the National Institute for Soil Science (Ministry of Agriculture).

The Ministry of Higher Education and Research runs an extension programme called Centres for Research and Experimentation to promote technology transfer. These centres popularize innovative research that improves social welfare.

Several research funds, including one targeting women

The public sector uses a variety of instruments to fund research:

- the Impulse Fund for Scientific and Technical Research, set up in 1973 and transformed in 2015 into the National Fund for Research and Innovation;
- the Project for Supporting and Promoting Female Teachers and Researchers in Senegal (2013), which only funds women applicants;

18. *See:* www.youwin.org.ng

- the National Fund for Agricultural and Food Research, set up in 1999, which funds research and the commercialization of results for users; and
- the Fund for Scientific and Technical Publications, set up in the 1980s.

SIERRA LEONE

Inclusive, green and middle-income by 2035

Sierra Leone also aspires to become 'an inclusive, green middle-income country by 2035', in the words of the country's *Agenda for Prosperity: the Road to Middle Income Status, 2013–2018.*[19] Current GDP per capita may be only US$ 809 per year but the fact that GDP progressed by 20.1% in 2013 gives cause for hope of realizing this goal. Sierra Leone has, of course, been struggling with the Ebola epidemic. Some 95 health workers have died, a sad reminder of the country's inadequate health facilities: there is just one doctor for 50 000 people.

Among the *Agenda for Prosperity's* objectives to 2035, those which will depend upon science and technology include*:*

- a health care and delivery system within a 10-km radius of every village;
- modern infrastructure with reliable energy supplies;
- world-standard ICTs (just 1.7% of the population had internet access in 2013);
- private-sector led growth creating value-added products;
- an effective environmental management system in place that protects biodiversity and is capable of pre-empting environmental disasters;
- becoming a model in responsible and efficient natural resource exploitation.

In 2006, the Ministry of Education, Science and Technology engaged a participatory process for the drafting of the *Sierra Leone Education Sector Plan: a Road to a Better Future* (2007–2015). The *Plan* emphasizes human resource development, starting with the bottom of the pyramid. Despite this laudable intention, public expenditure on education only increased from 2.6% to 2.9% of GDP between 2007 and 2012. The share devoted to tertiary education likewise rose little: from 19% to 22% of total expenditure on education (0.7% of GDP in 2012). In the *Plan*, the ministry projected that student enrolment in public universities would rise to about 15 000 by 2015 and to 9 750 in private and distance institutions offering vocational training, including for teachers (MoEdST, 2007).

Fourah Bay College, founded in 1827, is the oldest Western-type university in West Africa. Currently, it is part of the University of Sierra Leone, the country's only university boasting a Faculty of Engineering and a Faculty of Pure and Applied Sciences.

TOGO

A first STI policy

In July 2014, Togo took a major step by developing its first *National Policy for Science, Technology and Innovation* and the action plan for its implementation. In addition, a Presidential Council on the Future of Higher Education and Research was established, following a national consultation. Togo has identified such a wide range of priority research areas that they encompass almost all scientific fields: agriculture, medicine, natural sciences, humanities, social sciences and engineering and technology.

The Ministry of Higher Education and Research is responsible for implementing science policy, in tandem with the Directorate for Scientific and Technical Research, which is in charge of co-ordination and planning.

Togo does not have a biotechnology policy but it does have a framework for biosafety. In April 2014, the Ministry of Environment and Forest Resources organized a consultative workshop to align Togo's revised biosafety law with international biosafety regulations and best practices (Box 18.1).

Togo's main research centres are the Universities of Lomé and Kara, together with the Institute for Agronomic Research, which manages an extension service. To date, though, the country has neither a structure for promoting research and technology transfer, nor any funding to drive it.

The country faces a host of other challenges, including poorly equipped – or even totally unequipped – laboratories, an unattractive working environment for scientists and a lack of information.

CONCLUSION

Research networks need sustainable funding

The overall development goal for ECOWAS countries is to attain lower or upper middle-income status. This ambition permeates their respective development plans and policies. Even for those countries which have moved into the middle-income bracket, there is the fundamental challenge of diversifying the economy and ensuring that wealth creation impacts positively on the lives of all citizens. Development entails building roads and hospitals, expanding railways, installing telecommunications,

19. This document follows on from *Agenda for Change, 2007–2012.*

developing a reliable, responsible energy network, improving agricultural productivity, producing value-added goods, improving sanitation systems and so on. Any one of these areas needs science or engineering, or both.

Countries have made a big effort in recent years to expand their university and research networks. These institutions must not remain empty shells. They must be nurtured, staffed with competent people who have the means to dispense quality education and conduct creative research that is responsive to socio-economic problems and market needs. That necessitates sustainable investment. In this regard, Nigeria's tax on businesses for use in upgrading universities serves as an interesting funding model that could be replicated in other West African countries which host multinationals.

ECOWAS countries are formulating beautifully crafted policies and programmes but these must also be implemented, funded and monitored, so that progress can be measured and future plans adapted to the shifting reality. New scientific programmes are emerging that are well-designed and well-funded, like the African Centres of Excellence (Table 18.1). Hopefully, these programmes will create a momentum that will have a lasting impact on these countries and the wider subregion.

In our view, there are five main challenges for the years to come. West African governments need to:

- invest more in science and engineering education, in order to develop the skilled labour force necessary to become a middle-income country within 20 years; the number of engineers and agricultural researchers is particularly low in most countries;
- establish viable national S&T policies, in other words, policies that are accompanied by an implementation plan that foresees an evaluation of implementation and a relevant funding mechanism for research and the commercialization of results;
- make a greater effort to reach the national target of devoting 1% of GDP to R&D, if they are serious about becoming middle-income countries within 20 years; greater government investment would have the advantage of allowing researchers to work on topics of national interest rather than those proposed by donors;
- encourage the business sector to participate more actively in R&D , in order to stimulate demand for knowledge production and technological development, while reducing budgetary pressure on governments, which tend to bear the greatest funding burden for R&D, along with donors; in this context, governments which have not yet done so should put in place national funds to help local innovators protect their intellectual property rights, as recommended by ECOPOST; other measures could include making provision for representatives of the private sector to sit on the governing boards of universities and research institutes, as Senegal has done (see p. 494), tax incentives to support business innovation, the creation of science and technology parks and business incubators to encourage start-ups and public–private partnerships and research grants to support collaborative research between the government, industry and academia in priority areas;
- foster exchanges and intraregional collaboration among West African researchers, while maintaining partnerships beyond the subregion, in order to ensure the quality and impact of scientific production; the African Centres of Excellence project and the WAEMU centres of excellence offer a golden opportunity for researchers across the region to 'put their heads together' to solve common development problems and respond to market needs.

KEY TARGETS FOR SUB-SAHARAN AFRICA

- Raise GERD to 1% of GDP in all ECOWAS countries;
- Raise the share of public expenditure on agriculture to 10% of GDP in all ECOWAS countries;
- Establish a national fund in each ECOWAS country to help local innovators protect their intellectual property;
- Establish a free trade area and customs union in each regional economic community by 2017 and across the entire continent by 2019;
- A continent-wide African Common Market to be operational by 2023;
- Put in place a continent-wide economic and monetary union by 2028, with a parliament and single currency to be managed by the African Central Bank.

REFERENCES

AfDB, OECD and UNDP (2014) *African Economic Outlook 2014*. African Development Bank, Organisation of Economic Cooperation and Development and United Nations Development Programme.

AOSTI (2014) *Assessment of Scientific Production in the African Union, 2005–2010*. African Observatory of Science, Technology and Innovation: Malabo, 84 pp.

ECOWAS (2011a) *ECOWAS Policy for Science and Technology: ECOPOST*. Economic Community for West African States.

ECOWAS (2011b) *ECOWAS Vision 2020: Towards a Democratic and Prosperous Society*. Economic Community for West African States.

Essayie, F. and B. Buclet (2013) Synthèse : Atelier-rencontre sur l'efficacité de la R&D au niveau des politiques et pratiques institutionnelles en Afrique francophone, 8–9 octobre 2013, Dakar. Organisation of Economic Cooperation and Development.

Gaillard, J. (2010) *Etat des lieux du système national de recherche scientifique et technique au Bénin*. Science Policy Studies Series. UNESCO **:** Trieste, 73 pp.

ISSER (2014) *The State of the Ghanaian Economy in 2013*. Institute of Statistical, Social and Economic Research. University of Ghana: Legon.

Juma, C. and I. Serageldin (2007) *Freedom to Innovate: Biotechnology in Africa's Development*. Report of High-level Panel on Modern Biotechnology.

MoEdST (2007) *Education Sector Plan – A Road Map to a Better Future, 2007–2015*. Ministry of Education, Science and Technology of Sierra Leone: Freetown.

MoEnST (2010) *National Science, Technology and Innovation Policy*. Ministry of Environment, Science and Technology of Ghana: Accra.

MoESC (2007) *Description du programme sectoriel de l'éducation 2008–2015*. Ministry of Education and Scientific Research of Guinea-Bissau: Conakry.
See: http://planipolis.iiep.unesco.org

MoHER (2013a) *Décisions présidentielles relatives à l'enseignement supérieur et à la recherche*. Ministry of Higher Education and Research of Senegal: Dakar, 7 pp.

MoHER (2013b) *Plan de développement de l'enseignement supérieur et de la recherche, 2013–2017*. Ministry of Higher Education and Research of Senegal: Dakar, 31 pp.

MoHERST (2013) *National Science, Technology and Innovation Policy*. Ministry of Higher Education, Research, Science and Technology of Gambia: Banjul.

MoSHESR (2009) *Document de politique nationale de l'enseignement supérieur et de la recherche scientifique*. Ministry of Secondary and Higher Education and Scientific Research of Mali: Bamako.
See http://planipolis.iiep.unesco.org

MRSI (2012) *Politique nationale de recherche scientifique et technique*. Ministry of Research, Science and Innovation of Burkina Faso: Ougadougou.

Nair–Bedouelle, S; Schaaper, M. and J. Shabani (2012) *Challenges, Constraints and the State of Science, Technology and Innovation Policy in African Countries*. UNESCO: Paris.

NPCA (2014) *African Innovation Outlook 2014*. Planning and Coordinating Agency of the New Partnership for Africa's Development: Pretoria, 208 pp.

NPCA (2011) *African Innovation Outlook 2011*. Planning and Coordinating Agency of the New Partnership for Africa's Development: Pretoria.

Oye Ibidapo, O. (2012) *Review of the Nigerian National System of Innovation*. Federal Ministry of Science and Tehchnology of Nigeria: Abuja.

Republic of Liberia (2012) *Agenda for Transformation: Steps Towards Liberia Rising 2030*. Monrovia.

University World News (2014) Effective research funding could accelerate growth. *Journal of Global News on Higher Education*. February, Issue no. 306.

Van Lill, M. and J. Gaillard (2014) *Science-granting Councils in sub-Saharan Africa. Country report: Côte d'Ivoire*. University of Stellenbosch (South Africa).

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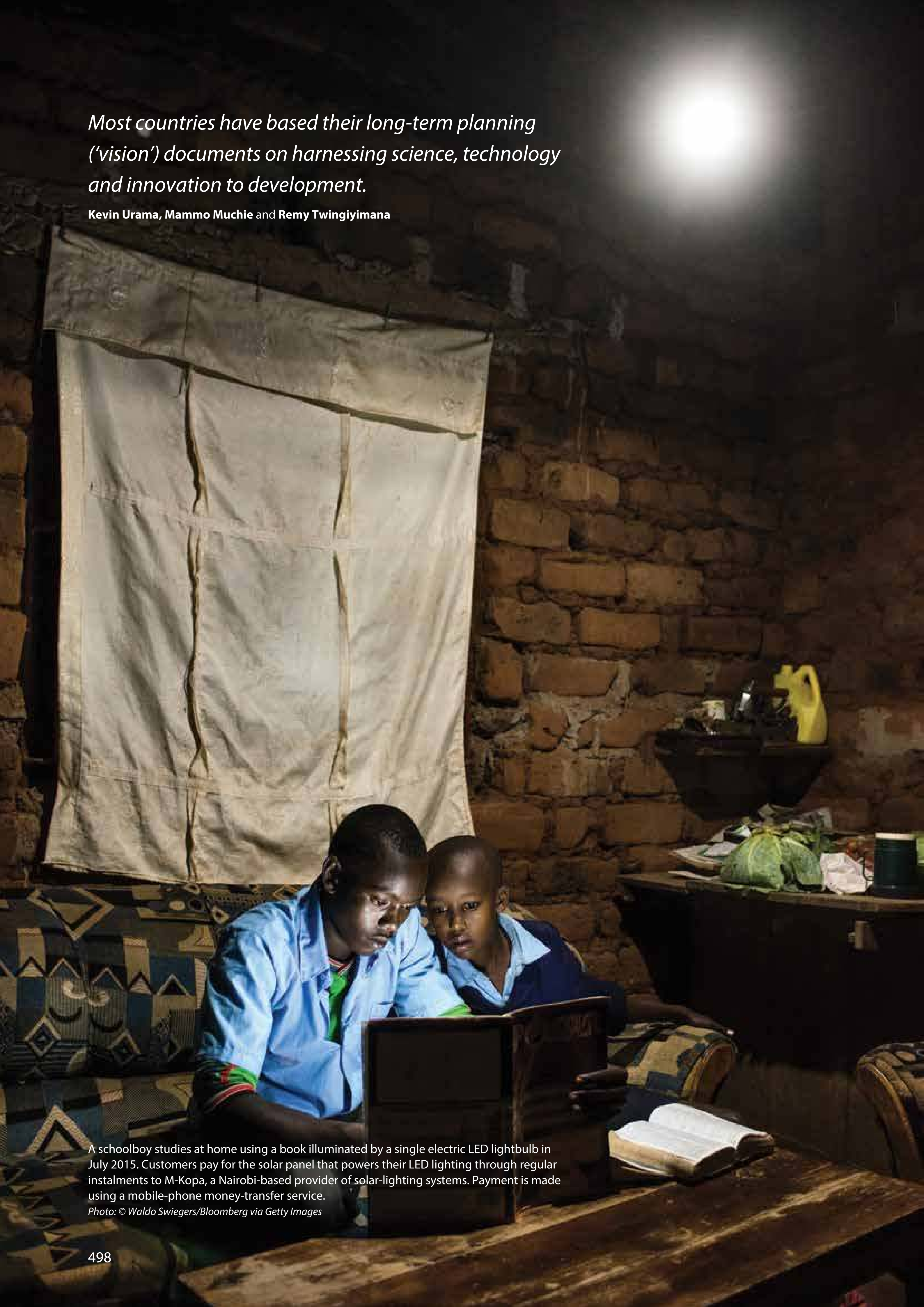
Most countries have based their long-term planning ('vision') documents on harnessing science, technology and innovation to development.

Kevin Urama, Mammo Muchie and **Remy Twingiyimana**



A schoolboy studies at home using a book illuminated by a single electric LED lightbulb in July 2015. Customers pay for the solar panel that powers their LED lighting through regular instalments to M-Kopa, a Nairobi-based provider of solar-lighting systems. Payment is made using a mobile-phone money-transfer service.
Photo: © Waldo Swiegers/Bloomberg via Getty Images

19 · East and Central Africa

Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo (Republic of), Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Kenya, Rwanda, Somalia, South Sudan, Uganda

Kevin Urama, Mammo Muchie and Remy Twiringiyimana

INTRODUCTION

Mixed economic fortunes

Most of the 16 East and Central African countries covered in the present chapter are classified by the World Bank as being low-income economies. The exceptions are Cameroon, the Republic of Congo, Djibouti and the newest member, South Sudan, which joined its three neighbours in the lower middle-income category after being promoted from low-income status in 2014. Equatorial Guinea is the region's only high-income country but this classification masks great variations in income levels; poverty is widespread and life expectancy at birth is among the region's lowest, at 53 years (Table 19.1).

All but four nations are classified as heavily indebted poor countries, the exceptions being Djibouti, Equatorial Guinea, Kenya and South Sudan. Poverty and high unemployment are endemic in the region. Life expectancy varies between 50 and 64 years, a strong indicator of the developmental challenges facing the region.

The region's economic fortunes have been a mixed bag since 2010. Several countries have managed to raise their GDP growth rates, or at least maintain them at 2004–2009 levels: Burundi, Chad, Comoros, Eritrea and Kenya. Two have sustained some of the highest growth rates in Africa – Cameroon and Ethiopia – and one recorded 24% growth in its first year of existence: South Sudan. Of note is that only two of these countries are oil-exporters: Chad and South Sudan.

Five of the continent's top 12 oil-producing countries are found in East and Central Africa (Figure 19.1). Economic growth is expected to slow down in Africa's oil-exporting countries, following a slump in Brent crude prices since mid-2014, as African exporters have fewer reserves than the Gulf States to tide them over until prices recover. Analysts suggest several explanations for the current drop in value of conventional sources of oil. On the one hand, clean energy policies have fostered the development of more fuel-efficient technology, including in the automotive industry. In parallel, technological developments in hydraulic fracturing (fracking) and horizontal drilling have made it profitable to extract oil from unconventional sources, such as tight rock formations [shale oil in the USA and oil (tar) sands in Canada], deep-sea oil (most countries are now finding deposits) and biofuels (Brazil and others); high global oil prices until recently have allowed countries which invest in these technologies to take a growing share of the global oil market. This highlights the need for oil-producing African countries to invest in science and technology (S&T) to maintain their own competitiveness in the global market.

Half the region is 'fragile and conflict-affected'

Other development challenges for the region include civil strife, religious militancy and the persistence of killer diseases such as malaria and HIV, which sorely tax national health systems and economic productivity. Poor governance and corruption undermine economic activity and foreign investment in several countries. Those which score poorly in Transparency International's Corruption Perceptions Index also tend to rank poorly in the Ibrahim Index of African Governance (Table 19.1): Burundi, Central African Republic, Chad, Republic of Congo, Eritrea, Somalia and South Sudan. Interestingly, both indices consider Rwanda as having the best governance record in East and Central Africa.

Seven countries are classified as 'fragile and conflict-affected' by the World Bank, namely Burundi, Central African Republic, Chad, Comoros, Eritrea, Somalia and South Sudan. In particular, the Central African Republic and South Sudan have experienced civil war in recent years. These conflicts tend to affect their neighbours as well, such as by disrupting trade flows, creating streams of cross-border refugees, or giving rise to cross-border attacks. For instance, South Sudanese have been seeking asylum in Uganda and the Boko Haram (literally, 'books are forbidden') sect in Nigeria has made violent incursions into neighbouring Cameroon and Niger and could threaten the trade route between Cameroon and Chad.

Meanwhile, Kenya's economy has suffered from terrorist attacks by the Somalian Al-Shabaab group which have undermined the country's important tourist industry, in particular. In April 2015, Al-Shabaab massacred 148 students and staff at Garissa University, the only such institution in the north of the country, which had only opened in 2011. Across the border, Somalia is engaged in a fragile process of state- and peacebuilding, its economy in ruins after two decades of political instability and insecurity.

In the Central African Republic, the economy has suffered considerably since late 2012 when rebel groups took control of towns in the centre and north of the country. Despite the deployment of peacekeepers from the African Union, United Nations and France and the signing of a ceasefire in July 2014, the situation remains volatile. For the first decade of the century, the country had experienced positive, albeit erratic, growth.

Table 19.1: **Socio-economic indicators for sub-Saharan Africa, 2014 or closest year**

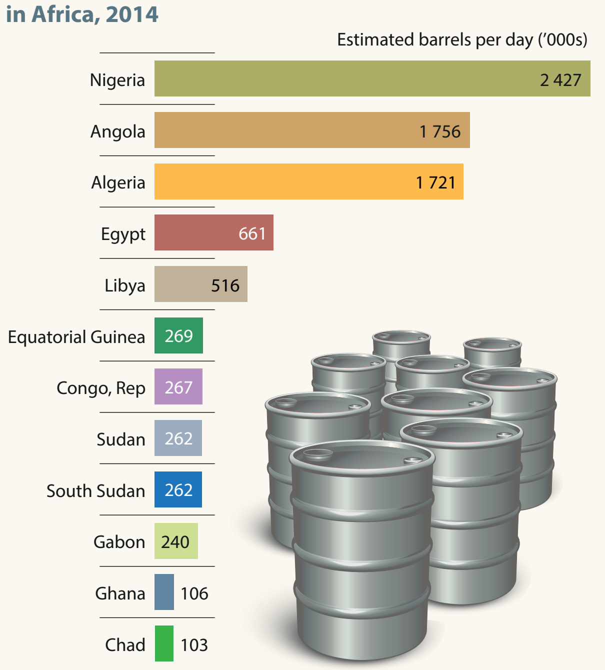
	Population ('000s), 2014	Annual population growth rate (%), 2014	Life expectancy at birth (years), 2013	GDP per capita (current PPP$), 2013	GDP growth rate (%), 2013	No of products accounting for more than 75% of exports, 2012	Ibrahim African governance Index, 2014	Access to improve d sanitation (%), 2011	Access to improved water, (%), 2011	Access to electricity (%), 2011	Internet access per 100 population, 2013	Mobile phone subscriptions per 100 population, 2013
Angola	22 137	3.05	51.9	7 736	6.80	1	44	88.6	93.9	99.4	19.10	61.87
Benin	10 600	2.64	59.3	1 791	5.64	9	18	5.0	57.1	28.2	4.90	93.26
Botswana	2 039	0.86	47.4	15 752	5.83	2	3	38.6	91.9	45.7	15.00	160.64
Burkina Faso	17 420	2.82	56.3	1 684	6.65	3	21	7.7	43.6	13.1	4.40	66.38
Burundi	10 483	3.10	54.1	772	4.59	3	38	41.7	68.8	–	1.30	24.96
Cabo Verde	504	0.95	74.9	6 416	0.54	8	2	–	–	–	37.50	100.11
Cameroon	22 819	2.51	55.0	2 830	5.56	6	34	39.9	51.3	53.7	6.40	70.39
Central African Republic	4 709	1.99	50.1	604	-36.00	4	51	14.6	58.8	–	3.50	29.47
Chad	13 211	2.96	51.2	2 089	3.97	1	49	7.8	39.8	–	2.30	35.56
Comoros	752	2.36	60.9	1 446	3.50	2	30	17.7	87.0	–	6.50	47.28
Congo, Rep.	4 559	2.46	58.8	5 868	3.44	1	41	–	–	37.8	6.60	104.77
Congo, Dem. Rep.	69 360	2.70	49.9	809	8.48	4	40	17.0	43.2	9.0	2.20	41.82
Côte d'Ivoire	20 805	2.38	50.8	3 210	8.70	10	47	14.9	76.0	59.3	2.60	95.45
Djibouti	886	1.52	61.8	2 999	5.00	7	35	61.4^{+1}	92.1^{+1}	–	9.50	27.97
Equatorial Guinea	778	2.74	53.1	33 768	-4.84	2	45	–	–	–	16.40	67.47
Eritrea	6 536	3.16	62.8	1 196	1.33	1	50	9.2	42.6	31.9	0.90	5.60
Ethiopia	96 506	2.52	63.6	1 380	10.49	6	32	2.4	13.2	23.2	1.90	27.25
Gabon	1 711	2.34	63.4	19 264	5.89	1	27	–	–	60.0	9.20	214.75
Gambia	1 909	3.18	58.8	1 661	4.80	4	23	–	75.8	–	14.00	99.98
Ghana	26 442	2.05	61.1	3 992	7.59	6	7	7.0	54.4	72.0	12.30	108.19
Guinea	12 044	2.51	56.1	1 253	2.30	2	42	8.3	52.4	–	1.60	63.32
Guinea-Bissau	1 746	2.41	54.3	1 407	0.33	1	48	–	35.8	–	3.10	74.09
Kenya	45 546	2.65	61.7	2 795	5.74	56	17	24.6	42.7	19.2	39.00	71.76
Lesotho	2 098	1.10	49.3	2 576	5.49	6	10	–	–	19.0	5.00	86.30
Liberia	4 397	2.37	60.5	878	11.31	8	31	–	–	–	4.60	59.40
Madagascar	23 572	2.78	64.7	1 414	2.41	30	33	7.9	28.6	14.3	2.20	36.91
Malawi	16 829	2.81	55.2	780	4.97	5	16	9.6	42.1	7.0	5.40	32.33
Mali	15 768	3.00	55.0	1 642	2.15	2	28	15.3	28.1	–	2.30	129.07
Mauritius	1 249	0.38	74.5	17 714	3.20	35	1	88.9	99.2	99.4	39.00	123.24
Mozambique	26 473	2.44	50.2	1 105	7.44	9	22	8.5	33.6	20.2	5.40	48.00
Namibia	2 348	1.92	64.3	9 583	5.12	8	6	23.6	67.2	60.0	13.90	118.43
Niger	18 535	3.87	58.4	916	4.10	3	29	4.8	34.3	–	1.70	39.29
Nigeria	178 517	2.78	52.5	5 602	5.39	1	37	36.9	45.6	48.0	38.00	73.29
Rwanda	12 100	2.71	64.0	1 474	4.68	5	11	30.2	60.3	–	8.70	56.80
Sao Tome & Principe	198	2.50	66.3	2 971	4.00	6	12	–	–	–	23.00	64.94
Senegal	14 548	2.89	63.4	2 242	2.80	25	9	35.1	59.9	56.5	20.90	92.93
Seychelles	93	0.50	74.2	24 587	5.28	4	5	97.1	96.3	–	50.40	147.34
Sierra Leone	6 205	1.84	45.6	1 544	5.52	4	25	10.9	36.7	–	1.70	65.66
Somalia	10 806	2.91	55.0	–	–	4	52	–	–	–	1.50	49.38
South Africa	53 140	0.69	56.7	12 867	2.21	83	4	58.0	81.3	84.7	48.90	145.64
South Sudan	11 739	3.84	55.2	2 030	13.13	1	–	–	–	–	–	25.26
Swaziland	1 268	1.45	48.9	6 685	2.78	21	24	48.5	38.9	–	24.70	71.47
Tanzania	50 757	3.01	61.5	2 443	7.28	27	19	6.6	55.0	15.0	4.40	55.72
Togo	6 993	2.55	56.5	1 391	5.12	11	15	13.2	48.4	26.5	4.50	62.53
Uganda	38 845	3.31	59.2	1 674	3.27	17	36	26.2	41.6	14.6	16.20	44.09
Zambia	15 021	3.26	58.1	3 925	6.71	3	13	41.3	49.1	22.0	15.40	71.50
Zimbabwe	14 599	3.13	59.8	1 832	4.48	9	46	40.6	79.2	37.2	18.50	96.35

+n = n years after reference year

Note: Not included in the African Governance column of this table are Algeria (20th), Egypt (26th), Libya (43rd), Mauritania (39th), Morocco (14th) or Tunisia (8th).

Source: World Bank's World Development Indicators, April 2015; for exports: AfDB, OECD & UNDP (2014) *African Economic Outlook 2014*; for African Governance Index: Mo Ibrahim Foundation (2014) *Ibrahim Index of African Governance – Country Profiles*: www.moibrahimfoundation.org; for water, sanitation and electricity: WHO, World Bank's World Development Indicators; UNICEF, UNDP and International Energy Agency, compiled by UNESCO

Figure 19.1: **Top 12 crude oil-producing countries in Africa, 2014**



Source: www.eia.gov

South Sudan's economic fortunes have been largely tied to its oil exports, which in turn have fluctuated wildly due to internal unrest and according to the state of political relations with neighbouring Sudan, through which its export pipeline runs. Over the past year, Equatorial Guinea has had to contend with stagnant world oil prices which have held its own GDP in check.

Ethiopia has been the shining star in the region, maintaining its double-digit growth rate over the past few years. Uganda has been another strong performer, although its growth seems to have been somewhat stunted by the slow global recovery from the 2008–2009 financial crisis. Eritrea has made some of the biggest gains, having managed to turn negative growth prior to 2010 into a 4.8% average ever since. On the whole, it does not appear as if the global crisis has had a major lasting impact on economies in the region, although the slowing-down of the Chinese economy since 2014 is a potential cause for concern for resource-exporting countries.

Regional integration can favour development

Most countries in East and Central Africa are still in the early stages of transition from traditional agrarian to modern industrial economies, as evidenced by the generally large contribution of agriculture to GDP (Figure 19.2). Agriculture even contributes more than half of GDP in Central African Republic, Chad and Sierra Leone. Notable exceptions to the rule are the Republic of Congo and Gabon, where the oil industry dwarfs all other economic activities.

Public spending on agriculture tends to be fairly low, at less than 5% of GDP for most countries (Table 19.2). This has obvious implications for expenditure on agricultural R&D as a subset of the total. So far, only three countries have reached the target in the *Maputo Declaration* (2003) of devoting 10% of GDP to agriculture: Burundi (10%), Niger (13%) and Ethiopia (21%). The large proportion of the working population employed in agriculture is another indicator of these countries' levels of development. The lack of economic diversification handicaps both agrarian and fossil-fuel based economies, as they tend to be heavily dependent on natural resources for foreign exchange, in particular.

Public expenditure on health is low in most countries, the exceptions being Burundi (4.4% of GDP), Djibouti (5.3%) and Rwanda (6.5%) in 2013. These same three countries also accord a high priority to education (more than 5% of GDP), as do Comoros (7.6% in 2008), the Republic of Congo (6.2% in 2010) and Kenya (6.7% in 2010).

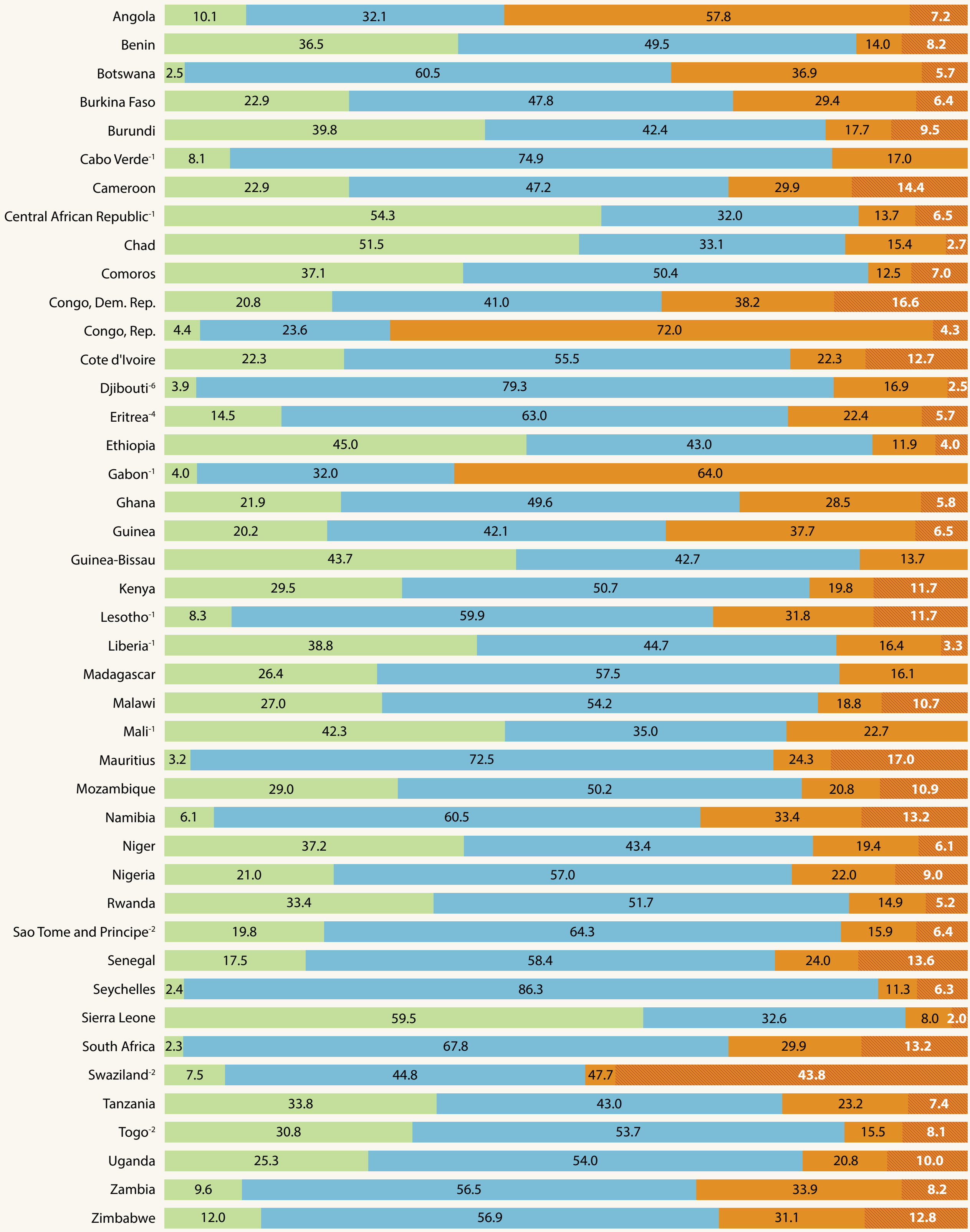
Military expenditure tends to account for less than 2% of GDP in the region, with the notable exception of Chad (2.0% in 2011), Burundi (2.2% in 2013), Central African Republic (2.6% in 2010), Djibouti (3.6% in 2008), Equatorial Guinea (4.0% in 2009) and, above all, South Sudan (9.3% in 2012) [Table 19.2].

The credibility of political institutions and election outcomes remains a major challenge. Owing to instability and governance challenges in East Africa, the region was the continent's lowest recipient of foreign direct investment (FDI) in 2008 and 2009. In 2013, FDI flowed most abundantly into the economies of Djibouti (19.6% of GDP), the Republic of Congo (14.5%) and Equatorial Guinea (12.3%). Whereas the oil industry was the main pole of attraction in the latter two countries, FDI flowed mostly into Djibouti's port area, which is strategically located on trade routes to the Middle East. The region's resource potential is expected to attract greater FDI flows in future. Potential areas for investment include oil and mineral exploration in Chad, Ethiopia, Sudan and Uganda, intensified economic and business reforms led by Rwanda and large infrastructure projects, such as the ongoing construction of the Ethiopian Grand Renaissance Dam and the development of geothermal energy in Kenya (see p. 524).

Intraregional trade is important for many small or landlocked East and Central African economies but it is severely hindered by the poor state of transport infrastructure. A major challenge will be to develop railway and road linkages to ports, so as to better connect countries with one another and the global economy.

Regional integration offers one means of addressing the challenges outlined above. Political co-operation is just as essential as economic co-operation, however, in order to

Figure 19.2: **Composition of GDP in sub-Saharan Africa by economic sector, 2013 (%)**



-n = data refer to *n* years before reference year

Agriculture | Services | Industry | Manufacturing as a subset of industry

Note: Data are unavailable for Equatorial Guinea, Gambia, Somalia and South Sudan.

Source: World Bank's World Development Indicators, April 2015

deal with civil, ethnic and cross-border conflicts, as well as to manage access to, and possible disputes over, natural resources that straddle national boundaries, including river catchments. The construction of the Ethiopian Grand Renaissance Dam on the Blue Nile illustrates the importance of intraregional dialogue. Once completed, it will be the largest hydroelectric power plant in Africa (6 000 MW) and the eighth-largest in the world. After Egypt expressed reservations, a Tripartite National Committee was set up with Sudan which met for the first time in September 2014. This led to the signing of a tripartite co-operation agreement in the Sudanese capital on 23 March 2015 which established the principle of energy-sharing by both upstream and downstream countries once the dam is completed. The ten points of the agreement were being debated in Egypt and Ethiopia in mid-2015.

Regional integration also offers an opportunity for greater solidarity in an emergency situation. One illustration of this new paradigm is the decision by the East African Community in October 2014 to send a contingent of 600 health professionals to West Africa, including 41 doctors, to combat the Ebola epidemic (see p. 472).

A step closer to regional integration

There are three main regional economic communities in East Africa: the Common Market for Eastern and Southern Africa (COMESA[1]), the East African Community (EAC) and the Intergovernmental Authority on Development (IGAD). There is quite a lot of overlap, with many member states belonging to more than one regional trade bloc. Djibouti, Eritrea, Ethiopia and Sudan belong to both COMESA and IGAD, for instance, Burundi and Rwanda to both COMESA and EAC and Kenya and Uganda to all three. Some countries also belong to the Southern African Development Community (SADC), such as Tanzania, which is a member of the EAC. This overlap can potentially strengthen regional co-operation, as long as the various blocs co-ordinate their policies. The ultimate goal for the African Union is to develop an African Economic Community by 2023 (see Box 18.2).

The EAC was established in 1967 but collapsed in 1977 before being resuscitated in 2000. COMESA was founded in 1993 as the successor to the Preferential Trade Area for Eastern and Southern Africa. Both founding treaties make provisions for co-operation to develop STI. A number of East and Central African countries have also entered into bilateral co-operation agreements with South Africa in science and technology, most recently Ethiopia and Sudan in 2014 (see Table 20.6).

1. For the members of these regional communities, see Annex 1. Tanzania is profiled in Chapter 20 on the SADC countries, see p. 559

The Inter-University Council for East Africa (IUCEA) was formally integrated into the operational framework of the EAC by the East African Legislative Assembly in 2009 through the IUCEA Act. IUCEA has been entrusted with the mission of developing a Common Higher Education Area by 2015. In order to harmonize higher education systems in EAC countries, IUCEA established the East African Quality Assurance Network in 2011, which is in the process of developing a regional policy and an East African qualifications framework for higher education. IUCEA also established a partnership with the East African Business Council in 2011 to foster joint research and innovation by the private sector and universities and identify areas for curricular reform. The two partners organized the region's first forum for academia and private firms under the auspices of the EAC in Arusha in 2012 and a second with the East African Development Bank in Nairobi in 2013.

On 1 July 2010, the five EAC members – Burundi, Kenya, Rwanda, Tanzania and Uganda – formed a common market; the agreement provides for the free movement of goods, labour, services and capital. In 2014, Rwanda, Uganda and Kenya agreed to adopt a single tourist visa. Kenya, Tanzania and Uganda have also launched the East African Payment System. On 30 November 2013, the EAC countries signed a Monetary Union Protocol with the aim of establishing a common currency within 10 years.

The EAC *Common Market Protocol* (2010) makes provisions for market-led research, technological development and the adaptation of technologies in the community, in order to support the sustainable production of goods and services and enhance international competitiveness. States are to collaborate with the East African Science and Technology Commission and other institutions to develop mechanisms for commercializing indigenous knowledge and ensuring intellectual property protection. Member states also undertake to establish a research and technological development fund for the purpose of implementing the provisions in the protocol. Other clauses include:

- promoting linkages among industries and other economic sectors within the EAC community;
- promoting industrial R&D and the transfer, acquisition, adaptation and development of modern technology;
- promoting sustainable and balanced industrialization to cater for the least industrialized members;
- facilitating the development of micro-, small and medium-sized (SME) enterprises and promoting indigenous entrepreneurs; and
- promoting knowledge-based industries.

Table 19.2: **Investment priorities in sub-Saharan Africa, 2013 or closest year**

	Military expenditure (% of GDP), 2013	Public health expenditure (% of GDP), 2013	Public expenditure on agriculture (% of GDP), 2010	Public expenditure on education (% of GDP), 2012	Government expenditure on tertiary education (% of GDP), 2012	Expenditure on tertiary education (% total public expenditure on education), 2012	FDI inflows (% of GDP), 2013
Angola	4.9	2.5	<5	3.5^{-2}	0.2^{-6}	8.7^{-6}	-5.7
Benin	1.0	2.5	<5	5.3^{-2}	0.8^{-2}	15.6^{-2}	3.9
Botswana	2.0	3.1	<5	9.5^{-3}	3.9^{-3}	41.5^{-3}	1.3
Burkina Faso	1.3	3.7	11	3.4^{-1}	0.8	20.2^{-1}	2.9
Burundi	2.2	4.4	10	5.8	1.2	20.6	0.3
Cabo Verde	0.5	3.2	<5	5.0^{-1}	0.8^{-1}	16.6^{-1}	2.2
Cameroon	1.3	1.8	<5	3.0	0.2	7.8	1.1
Central African Republic	2.6^{-3}	2.0	<5	1.2^{-1}	0.3^{-1}	27.3^{-1}	0.1
Chad	2.0^{-2}	1.3	6	2.3^{-1}	0.4^{-1}	16.3^{-1}	4.0
Comoros	–	1.9	–	7.6^{-4}	1.1^{-4}	14.6^{-4}	2.3
Congo, Rep.	1.1^{-3}	3.2	–	6.2^{-2}	0.7^{+1}	10.9^{-2}	14.5
Congo, Dem. Rep.	1.3	1.9	–	1.6^{-2}	0.4^{-2}	24.0^{-2}	5.2
Côte d'Ivoire	1.5^{-1}	1.9	<5	4.6^{-4}	0.9^{-5}	21.0^{-5}	1.2
Djibouti	3.6^{-5}	5.3	–	4.5^{-2}	0.7^{-2}	16.5^{-2}	19.6
Equatorial Guinea	4.0^{-4}	2.7	<5	–	–	–	12.3
Eritrea	–	1.4	–	2.1^{-6}	–	–	1.3
Ethiopia	0.8	3.1	21	4.7^{-2}	0.2^{-2}	3.5^{-2}	2.0
Gabon	1.3	2.1	–	–	–	–	4.4
Gambia	0.6^{-6}	3.6	8	4.1	0.3	7.4	2.8
Ghana	0.5	3.3	9	8.1^{-1}	1.1^{-1}	13.1^{-1}	6.7
Guinea	–	1.7	–	2.5	0.8	33.4	2.2
Guinea-Bissau	1.7^{-1}	1.1	<5	–	–	–	1.5
Kenya	1.6	1.9	<5	6.6^{-2}	1.1^{-6}	15.4^{-6}	0.9
Lesotho	2.1	9.1	<5	13.0^{-4}	4.7^{-4}	36.4^{-4}	1.9
Liberia	0.7	3.6	<5	2.8	0.1	3.6	35.9
Madagascar	0.5	2.6	8	2.7	0.4	15.2	7.9
Malawi	1.4	4.2	28	5.4^{-1}	1.4^{-1}	26.6^{-1}	3.2
Mali	1.4	2.8	11	4.8^{-1}	1.0^{-1}	21.3^{-1}	3.7
Mauritius	0.2	2.4	<5	3.5	0.3	7.9	2.2
Mozambique	0.8^{-3}	3.1	6	5.0^{-6}	0.6^{-6}	12.1^{-6}	42.8
Namibia	3.0	4.7	<5	8.5^{-2}	2.0^{-2}	23.1^{-2}	6.9
Niger	1.1^{-1}	2.4	13	4.4	0.8	17.6	8.5
Nigeria	0.5	1.1	6	–	–	–	1.1
Rwanda	1.1	6.5	7	4.8	0.6	13.3	1.5
Sao Tome & Principe	–	2.0	7	9.5^{-2}	–	–	3.4
Senegal	0.002	2.2	14	5.6^{-2}	1.4^{-2}	24.6^{-2}	2.0
Seychelles	0.9	3.7	<5	3.6^{-1}	1.2^{-1}	32.5^{-1}	12.3
Sierra Leone	0.001	1.7	<5	2.9	0.7	23.2	3.5
South Africa	1.1	4.3	<5	6.6	0.8	11.9	2.2
South Sudan	9.3^{-1}	0.8	–	0.7^{-1}	0.2^{-1}	25.3^{-1}	–
Swaziland	3.0	6.3	5	7.8^{-1}	1.0^{-1}	12.8^{-1}	0.6
Tanzania	0.9	2.7	7	6.2^{-2}	1.7^{-2}	28.3^{-2}	4.3
Togo	1.6^{-2}	4.5	9	4.0	1.0	26.1	1.9
Uganda	1.9	4.3	<5	3.3	0.4	11.5	4.8
Zambia	1.4	2.9	10	1.3^{-4}	0.5^{-7}	25.8^{-7}	6.8
Zimbabwe	2.6	–	–	2.0^{-2}	0.4^{-2}	22.8^{-2}	3.0

-n/+n: data refer to n years before or after reference year

Source: for education: UNESCO Institute for Statistics; for agriculture: ONE.org (2013) *The Maputo Commitments and the 2014 African Union Year of Agriculture*; for all other variables: World Bank's World Development Indicators, April 2015

Fourteen out of 20 COMESA members have formed a free-trade zone since 2000 (see Box 18.2). This agreement has facilitated trade in the tea, sugar and tobacco sectors, in particular. Intra-industry linkages have also evolved considerably, with trade in semi-manufactured goods among member states having overtaken trade in similar products with the rest of the world. In 2008, COMESA agreed to expand its free-trade zone to include EAC and SADC members. Negotiations are currently under way for a COMESA–EAC–SADC Tripartite Free Trade Agreement by 2016.

The Intergovernmental Authority on Development (IGAD) was created in 1996 to supersede the Intergovernmental Authority on Drought and Development, which had been founded by Djibouti, Ethiopia, Kenya, Somalia, Sudan and Uganda in 1986, after a severe famine. Eritrea and South Sudan joined IGAD after gaining independence in 1993 and 2011 respectively. The IGAD Climate Prediction and Applications Centre, based in Nairobi, Kenya, began life as the Drought Monitoring Centre in 1989, before being fully integrated into IGAD through a related protocol in 2007. In addition to the eight IGAD countries, the centre counts Burundi, Rwanda and Tanzania among its members. More recently, the Regional Centre on Groundwater Resources Education, Training and Research in East Africa was set up at the Kenya Water Institute in Nairobi in 2011, under the auspices of UNESCO.

IGAD's current flagship programme (2013–2027) sets out to develop drought-resilient communities, institutions and ecosystems in the IGAD region by 2027. The seven thrusts of IGAD's Drought Resilience programme are:

- Natural resources and environment;
- Market access, trade and financial services;
- Livelihoods support and basic social services;
- Research, knowledge management and technology transfer;
- Conflict prevention, resolution and peace-building; and
- Co-ordination, institutional development and partnership.

TRENDS IN STI POLICY AND GOVERNANCE

An alignment with the continent's long-term vision

The programmes of COMESA, EAC and IGAD have been aligned with those of *Africa's Science and Technology Consolidated Plan of Action* (CPA, 2005–2014). When implementation of the CPA was reviewed in 2012, on the recommendation of the Fourth African Ministerial Conference on Science and Technology in Egypt (AMCOST, 2013)[2], the reviewers noted that 'the COMESA region has developed an innovation strategy which calls for a strong collaboration between COMESA and the NEPAD Agency and the African Union Commission in implementing the strategy.' They went on to say that 'the CPA has also been used as a template for formulating the science and technology policy for IGAD. In the East African Community, a programme from the CPA has been embedded into the health sector, leading to the launch of the African Medicines Regulatory Harmonization programme in March 2012.'

The SADC and the Economic Community of West Africa (ECOWAS) have also 'domesticated the Plan of Action:' the SADC adopted a *Protocol on Science, Technology and Innovation* in 2008 (see p. 537) and the CPA has informed the formulation of the *ECOWAS Policy on Science and Technology* (see p. 476).

The review of the CPA revealed significant achievements in the following areas:

- Establishment of four networks of centres of excellence within the African Biosciences Initiative (Box 19.1), as well as two complementary networks, Bio-Innovate (Box 19. 1) and the African Biosafety Network of Expertise (see Box 18.1);
- Establishment of a virtual African Laser Centre, which counted 31 member institutions in 2012;
- Establishment of the African Institutes of Mathematical Sciences (see Box 20.4);
- Establishment of the Southern Africa and West Africa Networks of Water Centres of Excellence;
- Launch of the African Science, Technology and Innovation Indicators Initiative;
- Establishment of the African Observatory for Science, Technology and Innovation in Equatorial Guinea;
- Launch of the African Medicines Regulatory Harmonization programme in the EAC in 2012;
- Introduction of African Union Competitive Research Grants administered by the African Union Commission – the first and second calls for research proposals took place in December 2010 and January 2012 for projects in post-harvest technologies and agriculture; renewable and sustainable energy; water and sanitation; fisheries and climate change;

2. This review was conducted by a high-level panel of eminent scientists supported by a group of experts from the African Academy of Sciences, AUC, NEPAD Agency, AfDB, UNECA, UNESCO and the International Council for Science, among others.

Box 19.1: **Networks of centres of excellence in biosciences**

In 2002, the Biosciences Eastern and Central Africa Network (BecA) became the first of four subregional hubs to be established by NEPAD, with support from the Canadian government. The hubs were set up within the African Biosciences Initiative, a cluster of three programmes for biodiversity science and technology, biotechnology and indigenous knowledge systems.

BecA manages the African Biosciences Challenge Fund, established in 2010. The fund has the dual function of capacity-building and R&D project-funding on a competitive basis. BecA runs training workshops and provides fellowships to scientists and graduate students from African national agricultural research organizations and universities.*

BecA regularly launches calls for researchers interested in implementing their projects over a maximum 12-month period at the network's hub, the International Livestock Research Institute in Nairobi. Priority research areas include improving control of priority livestock diseases; harnessing genetic diversity for conservation, resistance to disease and improved productivity; molecular breeding of important food security crops; plant–microbe interactions; orphan crops; the biological control of crop pests, pathogens and weeds; genomics and metagenomics; climate-smart forage grasses; mixed livestock–crop systems; and soil health.

A number of institutes have offered their facilities to the hub for regional use. These nodes are the University of Buea (Cameroon), Ethiopian Institute of Agricultural Research, National Agricultural Research Organization (Uganda); Kigali Institute of Science and Technology (Rwanda) and the University of Nairobi (Kenya).

BecA has established a wide range of partnerships, including with African Women in Agricultural Research and Development and the Association for Agricultural Research in Eastern and Central Africa. In 2012 and 2013, UNESCO funded the participation of 20 women scientists in the hub's Advanced Genomics and Bioinformatics workshops.

The Bio-Innovate network was set up in 2010 under BecA as a successor of BioEARN. It promotes the use of biosciences to improve crop productivity, smallholder farmers' resilience to climate change and to add value to local bio-resources by increasing the efficiency of the agro-processing industry. Funded by Sweden, the network covers Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda.

An encouraging evaluation

An evaluation of the fund by Dalbert Global Development Advisors published in April 2014 observed that the fund had 'achieved considerable growth and impact, reaching *circa* 500 individual scientists and researchers across the region over the past three years'. Some 30 FTE scientists were due to receive fellowships in 2014, the same number as the previous year. Among the 250 respondents to the evaluators' survey, 90% gave the hub a high score of 4.2 out of five for the quality of the facilities and training. One in three researchers (33%) and 43% of workshop participants between 2010 and 2013 were women, noted the report, a proportion the hub wished to raise to 50%. This offers the hub a 'unique opportunity to provide mentoring opportunities' for women, the report states, recalling that 'the majority of those who produce, process and market Africa's food are women'.

Of some concern was that one in four research staff indicated spending more than 50% of their time on administrative tasks. The report also noted that the hub remained financially vulnerable, with a small number of primary donors and no evidence to suggest that alumni would return in large numbers as fee-paying users of the hub's modern facilities. Up until now, the programme has been supported primarily by the Australian and Swedish governments, the Syngenta Foundation for Sustainable Agriculture and the Bill and Melinda Gates Foundation.

One of four African bioscience networks

From 2005 onwards, NEPAD established three other networks within the African Biosciences Initiative. These are the Southern African Network for Biosciences (SANbio), with its hub at the Council for Scientific and Industrial Research in Pretoria (South Africa); the West African Biosciences Network (WABNet), with its hub at the Institut sénégalais de recherches agricoles in Dakar (Senegal), and; the Northern Africa Biosciences Network (NABNet), based at the National Research Centre in Cairo (Egypt).

Each network has several nodes which co-ordinate R&D in a particular area. Those for SANBio, for instance, are Northwest University in South Africa (indigenous knowledge), the University of Mauritius (bioinformatics), Mauritius National Livestock Research Centre (livestock production), University of Namibia (mushroom production and commercialization for rural communities), University of Malawi–Bunda College (fisheries and aquaculture); and the SADC Plant Genetics Resources Centre in Zambia (gene banking). Research programmes have also been strengthened at other partner institutions within each network.

Source: http://hub.africabiosciences.org; www.nepad.org/humancapitaldevelopment/abi

*from Burundi, Cameroon, Central Africa Republic, Democratic Republic of Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Kenya, Madagascar, Rwanda, São Tomé & Príncipe, Somalia, South Sudan, Sudan, Tanzania and Uganda

- institutionalization of a biennial ministerial forum on STI, in partnership with UNESCO, the African Development Bank (AfDB) African Union Commission and United Nations Economic Commission for Africa (UNECA). The first forum took place in in Nairobi in April 2012, the second in Rabat in October 2014.

The review also identified the following shortfalls in CPA implementation, among others:

- The failure to set up the 'African Science and Technology Fund was one of the landmark and visible weaknesses in implementation of the CPA; the modest achievements recorded should be viewed in this context.' With hardly any governments having raised GERD to the target level of 1% of GDP, more than 90% of funding mobilized for implementation of the CPA came from bilateral and multilateral donors.
- STI priorities ought to have been linked to priorities of other development sectors to enhance impact.
- There should have been a differentiated approach to enable countries with limited human and infrastructural capacity (such as in post-conflict countries) to participate fully in CPA programmes.
- The lack of targets and a robust monitoring and evaluation strategy to track progress in implementation has led to minimal demonstration of the CPA's achievements. There should have been a strong, operational accountability framework for implementing partners.
- There was a limited focus on assessing how research efforts are contributing to solving needs in agriculture, food security, infrastructure, health, human capacity development and poverty reduction.
- Recent research on indigenous knowledge has mainly focused on documentation rather than sustainable exploitation.
- There has been inadequate linkage of the CPA to other continental frameworks and strategies.

Adopted by the African Union in 2014, the *Science, Technology and Innovation Strategy for Africa* (STISA-2024) is the first of five ten-year plans which intend to accelerate Africa's transition to an innovation-led, knowledge-driven economy by the year 2063 (*Agenda 2063*). STISA-2024 focuses on the following six priority areas:

- Eradication of hunger and achieving food security;
- Prevention and control of diseases;
- Communication (physical and intellectual mobility);
- Protecting our space;
- Living together – building society; and
- Wealth creation.

In order to achieve the objectives within these six priority areas, the following four pillars have been defined:

- Upgrading and/or building research infrastructure;
- Enhancing technical and professional competences;
- Innovation and entrepreneurship; and
- Providing an enabling environment for STI development in Africa.

STISA-2024 can learn from the review of the CPA. For instance, the reviewers considered a pan-African fund as being vital to sustain the networks of centres of excellence, encourage creative individuals and institutions to generate and apply science and technology and to promote technology-based entrepreneurship. Although STISA-2024 states that 'it is urgent to set up' an African Science and Technology Innovation Fund, it identifies no specific funding mechanism. Notwithstanding this, the African Union Commission has already heeded another of the review's recommendations by encouraging member countries to align their national and regional strategies on STISA-2024.

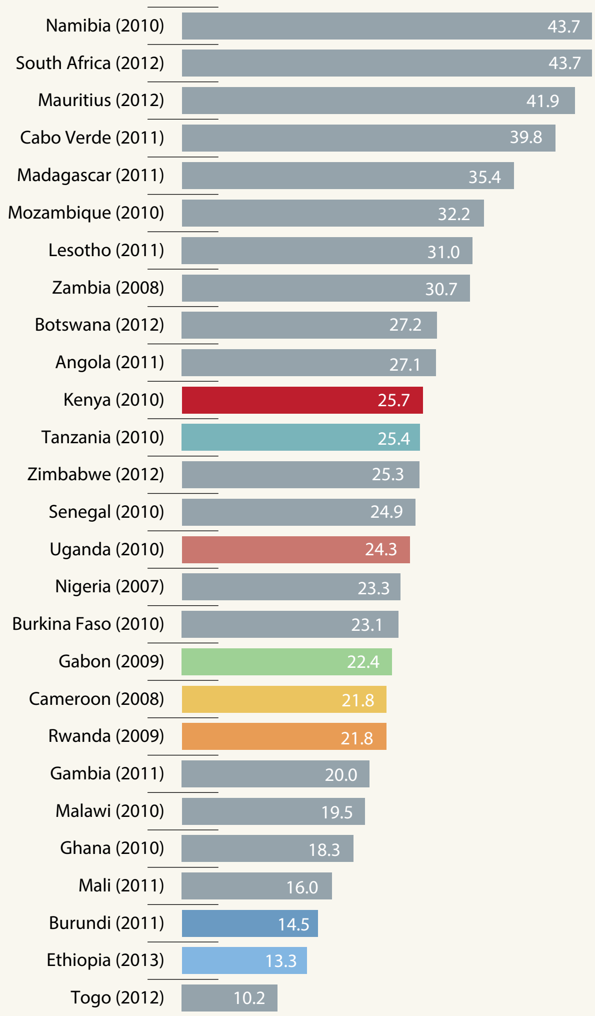
Gender equality on the development agenda

The 2012 review observed that, although the CPA did not have specific programmes in this area, implementing institutions had put initiatives in place to promote the role of women in STI. One initiative they cited were the regional scientific awards for women (US$ 20 000), which recompensed 21 recipients between 2009 and 2012. The EAC, ECOWAS, SADC and the Economic Community of Central African States have all participated in these awards.

A number of governments in East and Central Africa are also promoting gender equality in their policies and development plans. Examples are:

- Burundi's *Vision 2025* promises an energetic policy to promote gender equality and greater participation by women in education, politics and economic development. In 2011, 14.5% of researchers were women (Figure 19.3).
- Chad adopted a *National Policy on Gender* in 2011 which is being implemented by the Ministry of Social Action, Family and National Solidarity.
- In the Republic of Congo, a Ministry for the Promotion of Women and Integration of Women in National Development was established in September 2012.
- Ethiopia's *Growth and Transformation Plan 2011–2015* plans to raise the proportion of women university students to 40%. In 2013, 13.3% of researchers were women (Figure 19.3). The Ethiopian Minister of Science and Technology happens to be a woman, Demitu Hambisa.

Figure 19.3: **Women researchers in sub-Saharan Africa, 2013 or closest year (%)**



Note: Recent data are unavailable for some countries.

Source: UNESCO Institute for Statistics, April 2015

- Gabon adopted a *National Gender Equality and Equity Policy* in 2010. In 2009, 22.4% of researchers were women (Figure 19.3) and, in 2013, 16% of parliamentary seats were held by women (World Bank, 2013).
- In Rwanda, the Ministry of Gender and Family Promotion is situated in the Office of the Prime Minister. Rwanda's 2003 Constitution made provisions for a Gender Monitoring Office, which was established in 2007. The Constitution stipulates that both sexes should occupy no less than 30% of all decision-making bodies, thereby encouraging Rwandan women to compete for senior positions. Women won 51 out of the 80 seats (64%) in Rwanda's 2013 parliamentary elections, confirming Rwanda as world leader for this indicator. In research, however, women remain a minority (21.8% in 2009, Figure 19.3).
- The Government of Kenya produced a policy brief in 2014 on *Mainstreaming Gender in the National STI Policy of Kenya*, in partnership with UNESCO and the African Technology Policy Studies network; the policy brief served as an addendum to the draft National Science, Technology and Innovation Policy of 2012.

The emergence of technology and innovation hubs

In his blog for the World Bank, Tim Kelly observed in April 2014 that 'one of the key features of the African digital renaissance is that it is increasingly home-grown. In other sectors of the African economy, such as mining or agribusiness, much of the know-how is imported and the wealth extracted but Africa's 700 million or so mobile subscribers use services that are provided locally and they are also downloading more applications that are developed locally'.[3]

One of the main sources of locally developed applications are the technology hubs springing up across Africa (Figure 19.4). There are now over 90 such hubs across the continent, which vary in size and composition. Some have served as models, such as iHub in Kenya, BongoHive in Zambia, MEST in Ghana, the Co-creation hub in Nigeria and SmartXchange in South Africa. One of the more recent additions is the Botswana Innovation Hub (see p. 547).

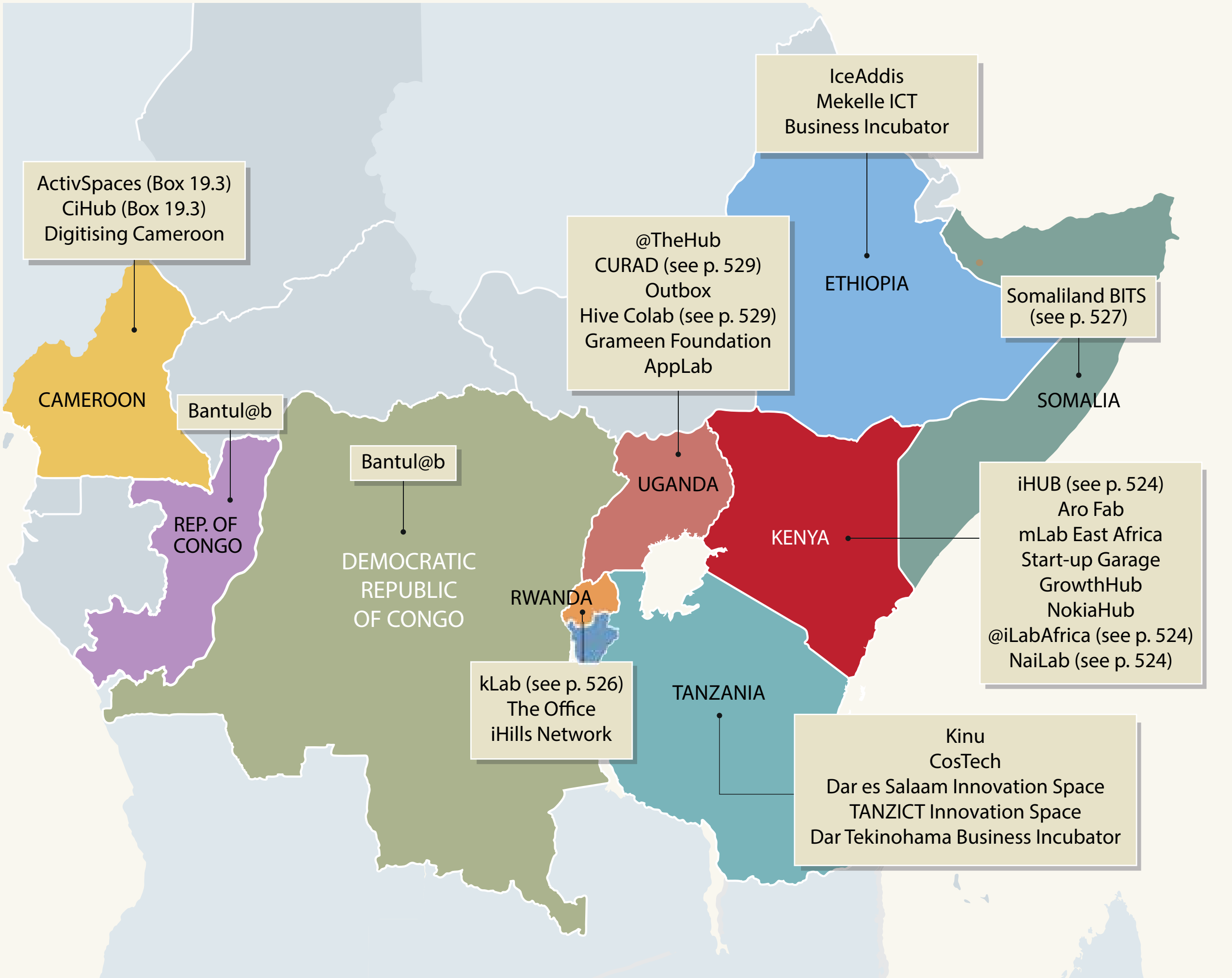
Spiralling from the MPesa, Kenya's money transfer service via a mobile phone, many applications have now been developed for different sectors ranging from agriculture and health to crowd-sourcing weather information for disaster risk reduction. While the impact of these technology hubs is yet to be systematically documented, an early prognosis is that this type of social innovation is already creating more prosperous societies in Africa (Urama and Acheampong, 2013).

Some of the start-ups graduating from incubators are tapping into the mobile phone app and banking revolution that is sweeping across East Africa. One example is MyOrder, an app which effectively enables street vendors to launch mobile web shops, with clients placing orders and making payments by mobile phone. Another app is Tusqee, which makes it possible for school administrators to send pupils' grades to their parents' phones (Nsehe, 2013).

If the start-ups cannot do it alone, neither can the technology incubators. Conscious of the economic impact of innovation, some governments are investing in the development of technology hubs. Kenya even plans to establish hubs in all 47 of its counties (see p.523). This is coherent with the adoption of policies in recent years which encompass innovation by Burundi in 2011, Ethiopia in 2010, Uganda in 2009 and Rwanda in 2005, among others.

3. See: http://blogs.worldbank.org/ic4d/tech-hubs-across-africa-which-will-be-legacy-makers

Figure 19.4: **Technology hubs in East and Central Africa, 2014**



Source: Adapted from iHB Research, World Bank and Bongohive

Persistently low internet penetration

Low internet penetration nevertheless prevents many East and Central African countries from seizing fully the opportunities offered by ICTs for socio-economic development. Penetration rates of less than 7% are found in Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo, Eritrea, Ethiopia and Somalia (Table 19.1). Kenya leads the region for this indicator, having realized the feat of raising internet penetration from 14% to 39% of the population between 2010 and 2013, a compound annual growth rate of 41%.

Mobile phone subscriptions are far more widespread, reaching from one-quarter (Burundi) to more than 200% (Gabon) of the population. Their ubiquity has inspired countless applications for mobile phones.

Prizes for science and innovation

A growing number of national and regional prizes have been introduced recently to encourage research and innovation. One example is the Olusegun Obasanjo Prize for Science and Innovation, named after the former president of Nigeria and implemented by the African Academy of Sciences. Also of note are the Annual Innovation Awards run by COMESA since February 2014 to celebrate individuals and institutions that have used STI to further the regional integration agenda.

Other actors are establishing prizes. In November 2014, the Moroccan Bank of Trade and Industry announced the creation of the African Entrepreneurship Award, with an endowment of US $1 million. This private bank operates in 18 African countries and around the world. In 2009, the annual Innovation Prize for Africa was established by the African Innovation Foundation, a Zurich-based, non-profit organization; the Innovation Prize is open to all Africans, with prize money valued at US$ 150 000. Now in its fourth year, the prize has been held in Ethiopia, South Africa and Nigeria. So far, it has attracted around 2 000 applications from 48 African countries.

TRENDS IN EDUCATION AND R&D

Generally low public spending on higher education

Public spending on education as a share of GDP varies considerably across the region (Table 19.2). The share of public education spending earmarked for tertiary education ranges from over 25% in some countries to just 3.5% in Ethiopia.

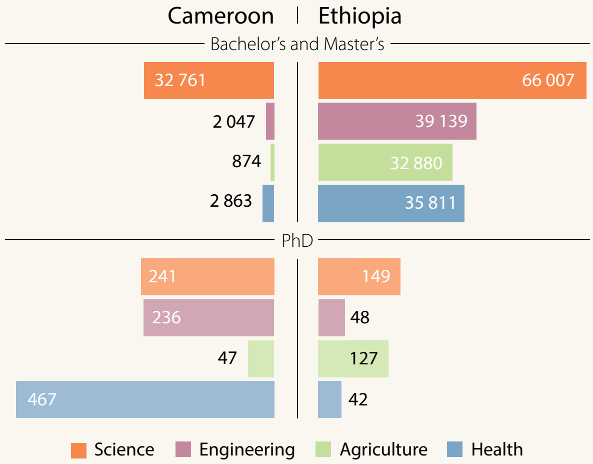
Primary school enrolment rates have grown in recent years in all countries for which data are available (Table 19.3). There is much greater variability in enrolment rates at secondary and tertiary levels; more than half of countries record secondary enrolment rates of less than 30% and, in the others, the enrolment of girls trails that of boys. Female secondary school enrolment rates remain below those of males in all but Rwanda and Comoros. At tertiary level, Cameroon, Comoros and Congo have recorded enrolment rates of over 10% in recent years, whereas Kenya's rate was a disappointing 4% at last count in 2009; Cameroon has recorded particularly rapid progress, raising its enrolment rate from 5.8% in 2005 to 11.9% in 2011. The gender disparity is also evident at tertiary level and is particularly pronounced in the Central African Republic, Chad, Eritrea and Ethiopia, where the male participation rate is more than 2.5 times higher than that for females (Table 19.3).

Data are only available by field of study for Cameroon and Ethiopia but these offer an interesting contrast. In both countries, most of those studying S&T at university were enrolled in scientific disciplines in 2010. The ratio of engineering to science students was much higher in Ethiopia (59%) than in Cameroon (6%). In Ethiopia, enrolment in agriculture was almost as high as in engineering or health sciences, whereas it was by far the least popular field of study in S&T in Cameroon (Figure 19.5), a state of affairs also observed in West and Southern Africa (see Chapters 18 and 20). The CPA review lamented the fact that young African researchers were reluctant to train in fields such as agricultural science which lacked popular appeal and was of the view that 'the shortage of qualified personnel in such fields was a big challenge for the continent.'

A greater R&D effort by some countries

In Kenya, gross domestic expenditure on research and development (GERD) is approaching the CPA target of 1% of GDP; it has also risen in recent years in Ethiopia (0.61%), Gabon (0.58%) and Uganda (0.48%) [Figure 19.6 and Table 19.5].

Figure 19.5: **Science and engineering students in Cameroon and Ethiopia, 2010**



Source: UNESCO Institute for Statistics, May 2015

Table 19.3: **Gross enrolment ratio for education in East and Central Africa, 2012 or closest year**

	Primary			Secondary			Tertiary		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Burundi	138.0	136.9	137.4	33.0	24.2	28.5	4.2^{-2}	2.2^{-2}	3.2^{-2}
Cameroon	117.9	103.2	110.6	54.3	46.4	50.4	13.7^{-1}	10.1^{-1}	11.9^{-1}
Central African R.	109.3	81.3	95.2	3.6	12.1	17.8	4.2	1.5	2.8
Chad	108.2	82.4	95.4	31.2	14.3	22.8	3.6^{-1}	0.9^{-1}	2.3^{-1}
Comoros	105.9^{+1}	99.9^{+1}	103.0^{+1}	62.8^{+1}	65.0^{+1}	63.9^{+1}	10.6	9.1	9.9
Congo, Rep.	105.5	113.4	109.4	57.5	49.8	53.7	12.7	8.0	10.4
Djibouti	73.1	65.9	69.5	49.4	38.1	43.8	5.9^{-1}	4.0^{-1}	4.9^{-1}
Equatorial Guinea	91.8	89.6	90.7	32.8^{-7}	23.6^{-7}	28.2^{-7}	–	–	–
Eritrea	–	–	–	–	–	–	3.0^{-2}	1.1^{-2}	2.0^{-2}
Ethiopia	93.4^{-6}	80.5^{-6}	87.0^{-6}	35.5^{-6}	22.3^{-6}	28.9^{-6}	4.2^{-7}	1.3^{-7}	2.8^{-7}
Kenya	114.1	114.6	114.4	69.5	64.5	67.0	4.8^{-3}	3.3^{-3}	4.0^{-3}
Rwanda	132.3	135.1	133.7	30.8	32.8	31.8	7.8	6.0	6.9
Somalia	37.6^{-5}	20.8^{-5}	29.2^{-5}	10.1^{-5}	4.6^{-5}	7.4^{-5}	–	–	–
South Sudan	102.9^{-1}	68.1^{-1}	85.7^{-1}	–	–	–	–	–	–
Uganda	106.5^{+1}	108.2^{+1}	107.3^{+1}	28.7^{+1}	25.0^{+1}	26.9^{+1}	4.9^{-1}	3.8^{-1}	4.4^{-1}

-n/+n: data refer to *n* years before or after reference year

Note: Gross enrolment includes pupils of all ages, including those below or above the official age for the given level of education. See also glossary, p. 738.

Source: UNESCO Institute for Statistics, May 2015

Table 19.4: **Tertiary enrolment by level of programme in sub-Saharan Africa, 2006 and 2012 or closest years**

	Year	Post-secondary non-degree	Bachelor's and master's	PhD or equivalent	Total tertiary	Year	Post-secondary non-degree	Bachelor's and master's	PhD or equivalent	Total tertiary
Angola	2006	0	48 694	0	48 694	2011	–	–	–	142 798
Benin	2006	–	–	–	50 225	2011	–	–	–	110 181
Botswana	2006	–	–	–	22 257	2011	–	–	–	39 894
Burkina Faso	2006	9 270	21 202	0	30 472	2012	16 801	49 688	2 405	68 894
Burundi	2006	–	–	–	17 953	2010	–	–	–	29 269
Cabo Verde	2006	–	–	–	4 567	2012	580	11 210	10	11 800
Cameroon	2006	14 044	104 085	2 169	120 298	2011	–	–	–	244 233
Central African Rep.	2006	1 047	3 415	0	4 462	2012	3 390	9 132	0	12 522
Chad	2005	–	–	–	12 373	2011	–	–	0	24 349
Comoros	2007	–	–	–	2 598	2012	–	–	0	6 087
Congo, Dem. Rep.	2006	–	–	–	229 443	2012	–	–	–	511 251
Congo, Rep.	–	–	–	–	–	2012	18 116	20 974	213	39 303
Côte d'Ivoire	2007	60 808	–	–	156 772	2012	57 541	23 008	269	80 818
Eritrea	–	–	–	–	–	2010	4 679	7 360	0	12 039
Ethiopia	2005	0	191 165	47	191 212	2012	173 517	517 921	1 849	693 287
Ghana	2006	27 707	82 354	123	110 184	2012	89 734	204 743	867	295 344
Guinea	2006	–	–	–	42 711	2012	11 614	89 559	0	101 173
Guinea-Bissau	2006	–	–	–	3 689	–	–	–	–	–
Kenya	2005	36 326	69 635	7 571	113 532	–	–	–	–	–
Lesotho	2006	1 809	6 691	0	8 500	2012	15 697	9 805	5	25 507
Liberia	–	–	–	–	–	2012	10 794	33 089	0	43 883
Madagascar	2006	9 368	37 961	2 351	49 680	2012	33 782	54 428	2 025	90 235
Malawi	2006	0	6 298	0	6 298	2011	–	–	–	12 203
Mali	–	–	–	–	–	2012	8 504	88 514	260	97 278
Mauritius	2006	9 464	12 497	260	22 221	2012	8 052	32 035	78	40 165
Mozambique	2005	0	28 298	0	28 298	2012	0	123 771	8	123 779
Namibia	2006	5 151	8 012	22	13 185	–	–	–	–	–
Niger	2006	2 283	8 925	0	11 208	2012	6 222	15 278	264	21 764
Nigeria	2005	658 543	724 599	8 385	1 391 527	–	–	–	–	–
Rwanda	2006	–	–	–	37 149	2012	–	–	0	71 638
Sao Tome & Principe	2006	0	0	0	0	2012	0	1 421	0	1 421
Senegal	2006	–	–	–	62 539	2010	–	–	–	92 106
Seychelles	2006	0	0	0	0	2012	–	–	–	100
South Africa	–	–	–	–	–	2012	336 514	655 187	14 020	1 005 721
Swaziland	2006	0	5 692	0	5 692	2013	0	7 823	234	8 057
Tanzania	2005	8 610	39 626	3 318	51 554	2012	–	142 920	386	166 014
Togo	2006	3 379	24 697	0	28 076	2012	10 002	55 158	457	65 617
Uganda	2006	–	–	–	92 605	2011	–	–	–	140 087
Zimbabwe	–	–	–	–	–	2012	26 175	–	–	94 012

Note: Data are unavailable for Equatorial Guinea, Gabon, Gambia, Sierra Leone, Somalia, South Sudan and Zambia.
Source: UNESCO Institute for Statistics, May 2015

The government tends to be the main source of R&D spending but the business enterprise sector contributes more than 10% of GERD in Gabon and Uganda (Table 19.5). Foreign sources contribute a sizeable share of GERD in Burundi (40%), Kenya (47%), Tanzania (42%) and Uganda (57%).

Although two R&D surveys have been published[4] since 2011 within Africa's Science, Technology and Innovation Indicators Initiative, there is a paucity of data on researchers in most of East and Central Africa. According to available data, Gabon and Kenya have the highest density of researchers by head count (Figure 19.7).

Distinct progress for the six most prolific countries

Four countries dominate scientific publishing (Cameroon, Ethiopia, Kenya and Uganda) but productivity is also rising in Gabon, the Republic of Congo and Rwanda, albeit from low levels (Figure 19.8). Gabon, Cameroon and Kenya count the most articles per million inhabitants but it is Ethiopia which has shown the most rapid progress, more than doubling its production since 2005 to take second place behind Kenya in terms of volume; Ethiopia's output remains modest, however, at just nine publications per million inhabitants.

The lion's share of articles focus on life sciences but research is growing in geosciences in Cameroon, Ethiopia, Kenya and Uganda. Of note is that Cameroon has a diverse research portfolio, leading the region for the number of Web of Science articles in chemistry, engineering, mathematics and physics in 2014. Overall, the growth in scientific publications in most countries reflects greater political support for S&T.

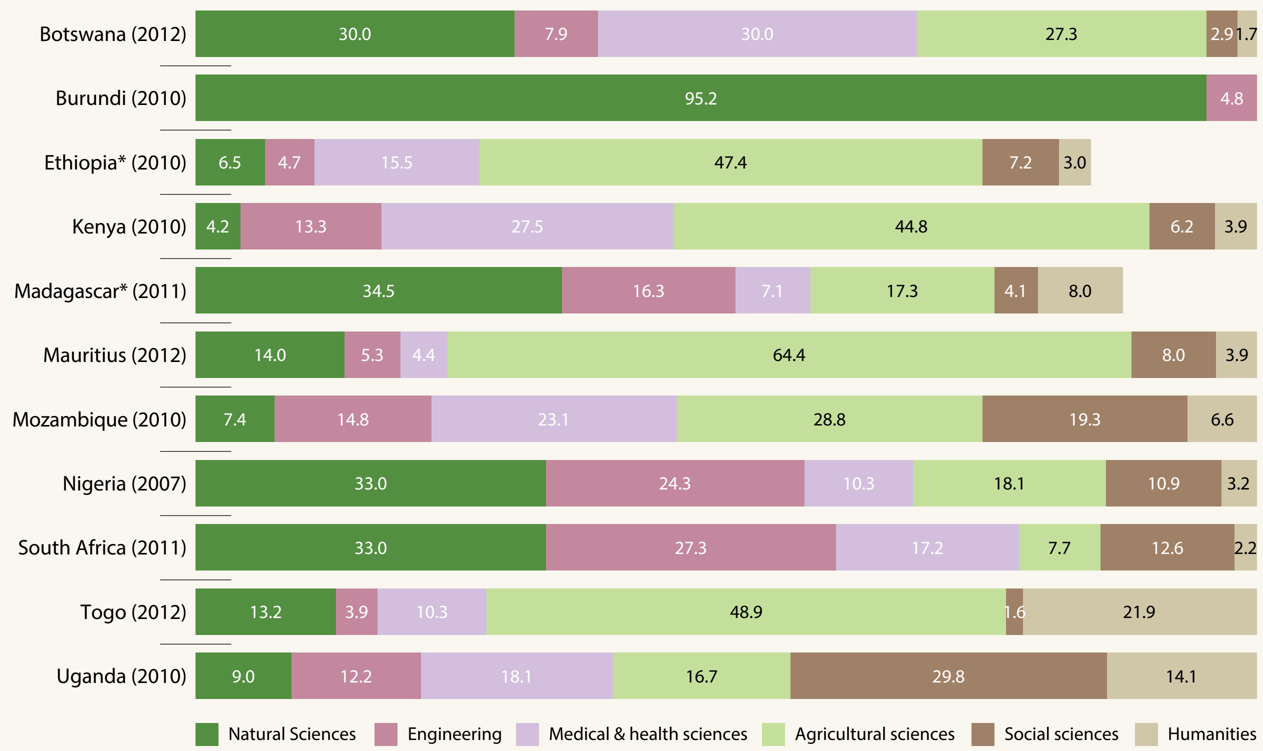
Very few patents since 2010

Only two ECA countries have obtained patents from the United States Patent and Trademark Office in the past five years. Cameroon registered four utility patents (for new inventions) in 2010, followed by three in 2012 and four in 2013. This is a dramatic improvement on the two patents generated by Cameroon in the period 2005–2009. The other country is Kenya; it registered seven utility patents between 2010 and 2013, which is nevertheless a marked decline from the 25 patents it received in the previous five-year period. No other types of patent (design, plant or reissue) have been granted since 2010, indicating that ECA countries continue to struggle to generate and register new inventions.

4. The first surveys were published in the *African Innovation Outlook* in 2011 and 2014. Funds have been secured from Sweden to 2017 for the third edition of the *Outlook*.

Figure 19.6: **GERD in sub-Saharan Africa by field of science, 2012 or closest year (%)**

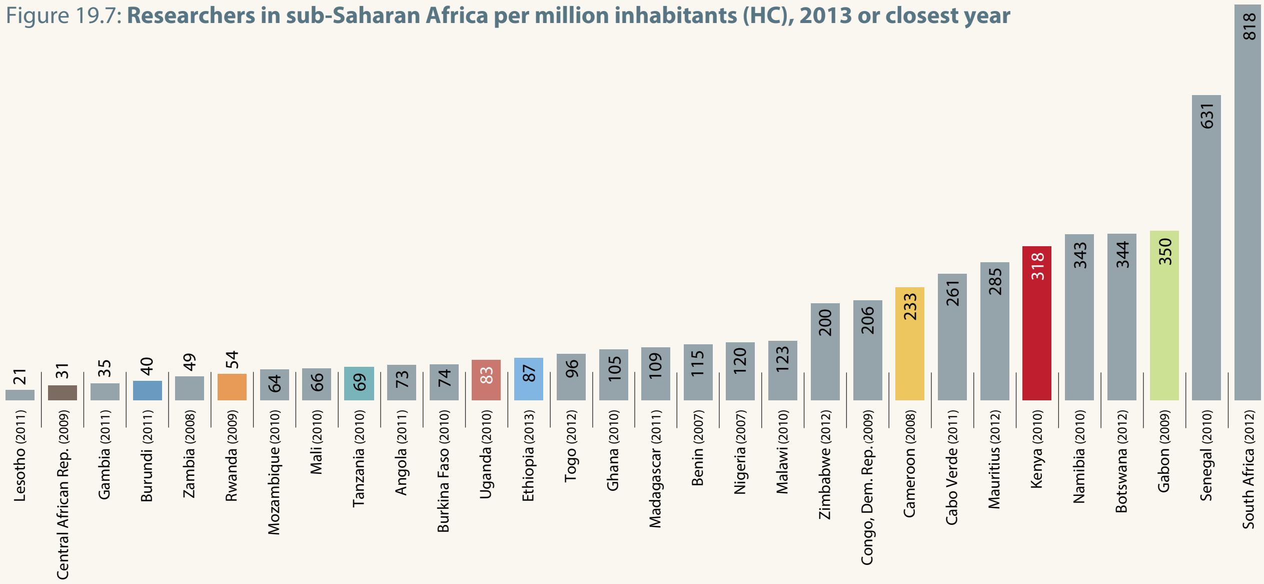
Available countries



*Whenever data do not add up to 100% for this indicator, it is because part of the data remain unattributed.

Source: UNESCO Institute for Statistics, April 2015

Figure 19.7: **Researchers in sub-Saharan Africa per million inhabitants (HC), 2013 or closest year**



Source: UNESCO Institute for Statistics, April 2015

Table 19.5: **GERD in sub-Saharan Africa, 2011**

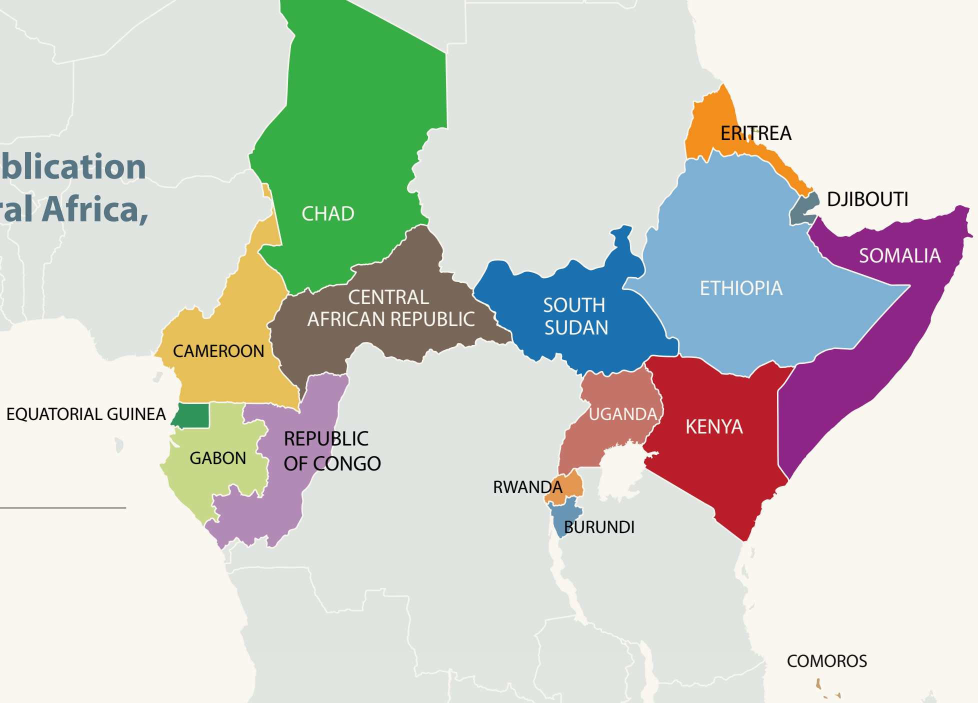
	GERD (% of GDP)	GERD per capita (current PPP$)	GERD per researcher (HC) in current PPP$ thousands	GERD by source of funds (%), 2011*				
				Business	Government	Higher education	Private non-profit	Abroad
Botswana	0.26^{+2}	37.8^{+2}	109.6^{+2}	5.8^{+2}	73.9^{+2}	12.6^{+2}	0.7^{+2}	6.8^{+2}
Burkina Faso	0.20^{-2}	2.6^{-2}	–	11.9^{-2}	9.1^{-2}	12.2^{-2}	1.3^{-2}	59.6^{-2}
Burundi	0.12	0.8	22.3	–	59.9^{-3}	0.2^{-3}	–	39.9^{-3}
Cabo Verde	0.07	4.5	17.3	–	100	–	–	–
Congo, Dem. Rep.	0.08^{-2}	0.5^{-2}	2.3^{-2}	–	100	–	–	–
Ethiopia	0.61^{+2}	8.3^{+2}	95.3^{+2}	0.7^{+2}	79.1^{+2}	1.8^{+2}	0.2^{+2}	2.1^{+2}
Gabon	0.58^{-2}	90.4^{-2}	258.6^{-2}	29.3^{-2}	58.1^{-2}	9.5^{-2}	-	3.1^{-2}
Gambia	0.13	2.0	59.1	–	38.5	–	45.6	15.9
Ghana	0.38^{-1}	11.3^{-1}	108.0^{-1}	0.1^{-1}	68.3^{-1}	0.3^{-1}	0.1^{-1}	31.2^{-1}
Kenya	0.79^{-1}	19.8^{-1}	62.1^{-1}	4.3^{-1}	26.0^{-1}	19.0^{-1}	3.5^{-1}	47.1^{-1}
Lesotho	0.01	0.3	14.3	–	–	44.7	–	3.4
Madagascar	0.11	1.5	13.3	–	100.0	–	–	–
Malawi	1.06^{-1}	7.8^{-1}	–	–	–	–	–	–
Mali	0.66^{-1}	10.8^{-1}	168.1^{-1}	–	91.2^{-2}	–	–	8.8-1
Mauritius	0.18^{+1}	31.1^{+1}	109.3^{+1}	0.3^{+1}	72.4^{+1}	20.7^{+1}	0.1^{+1}	6.4^{+1}
Mozambique	0.46^{-1}	4.0^{-1}	60.6^{-1}	-	18.8^{-1}	–	3.0^{-1}	78.1^{-1}
Namibia	0.14^{-1}	11.8^{-1}	34.4^{-1}	19.8^{-1}	78.6^{-1}	–	–	1.5^{-1}
Nigeria	0.22^{-4}	9.4^{-4}	78.1^{-4}	0.2^{-4}	96.4^{-4}	0.1^{-4}	1.7^{-4}	1.0^{-4}
Senegal	0.54^{-1}	11.6^{-1}	18.3^{-1}	4.1^{-1}	47.6^{-1}	0.0^{-1}	3.2^{-1}	40.5^{-1}
Seychelles	0.30^{-6}	46.7^{-6}	290.8^{-6}	–	–	–	–	–
South Africa	0.73^{+1}	93.0^{+1}	113.7^{+1}	38.3^{+1}	45.4^{+1}	0.8^{+1}	2.5^{+1}	13.1^{+1}
Tanzania	0.52^{-1}	7.6^{-1}	110.0^{-1}	0.1^{-1}	57.5^{-1}	0.3^{-1}	0.1^{-1}	42.0^{-1}
Togo	0.22^{+1}	3.0^{+1}	30.7^{+1}	-	84.9^{+1}	0.0^{+1}	3.1^{+1}	12.1^{+1}
Uganda	0.48^{-1}	7.1^{-1}	85.2^{-1}	13.7^{-1}	21.9^{-1}	1.0^{-1}	6.0^{-1}	57.3-1
Zambia	0.34^{-3}	8.5^{-3}	172.1^{-3}	–	–	–	–	–

-n/+n: data refer to *n* years before or after reference year
*Whenever data do not add up to 100% for this indicator, it is because part of the data remain unattributed.

Note: Data are missing for some countries.

Source: UNESCO Institute for Statistics, April 2015; for Malawi: UNESCO (2014) *Mapping Research and Innovation in the Republic of Malawi* (p. 57)

Figure 19.8: **Scientific publication trends in East and Central Africa, 2005–2014**



11.3%

Share of Kenyan papers among 10% most cited, 2008–2012; the G20 average is 10.2%

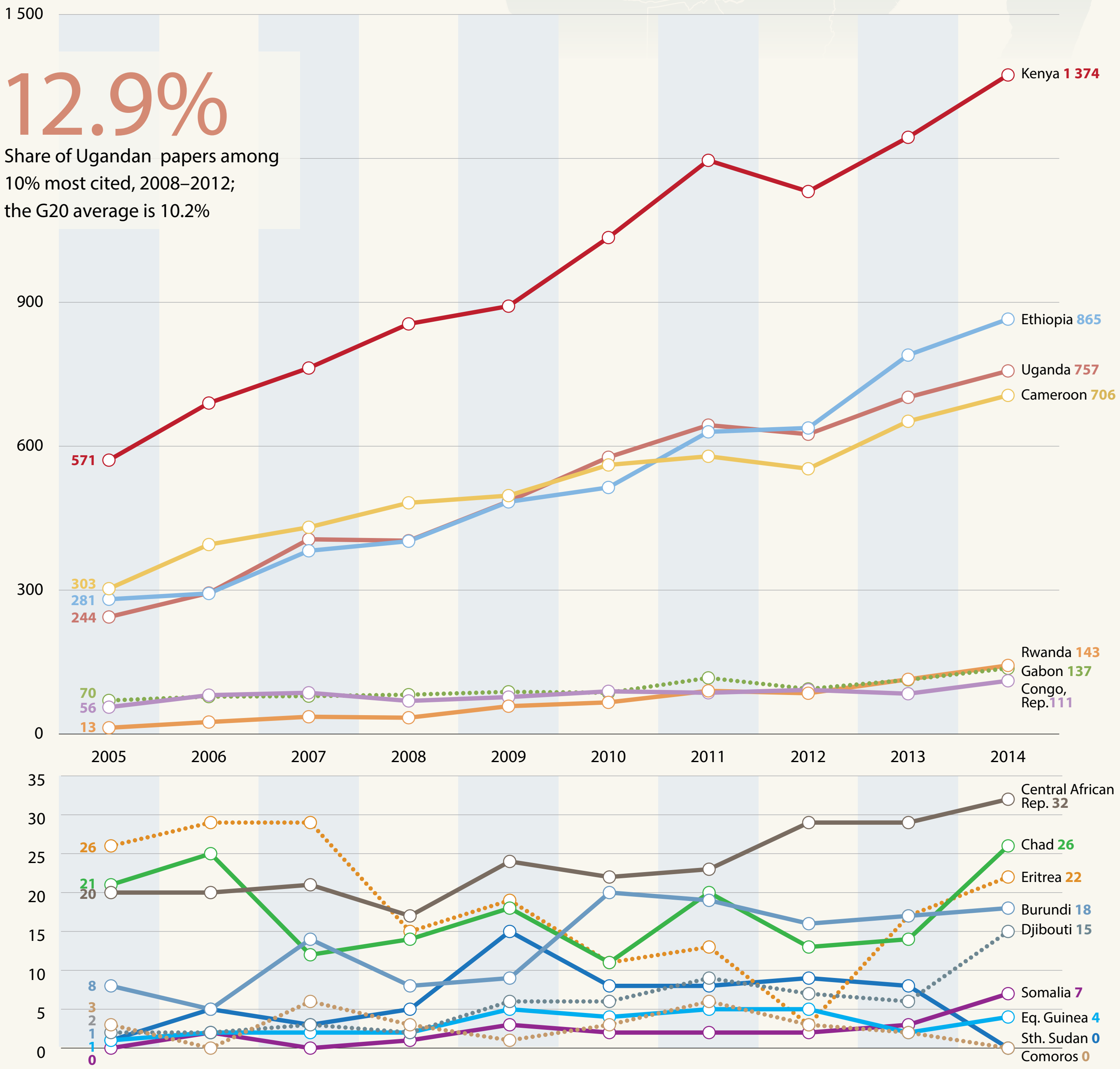
6.3%

Share of Ethiopian papers among 10% most cited, 2008–2012; the G20 average is 10.2%

Kenya, Ethiopia, Uganda and Cameroon produce the most publications

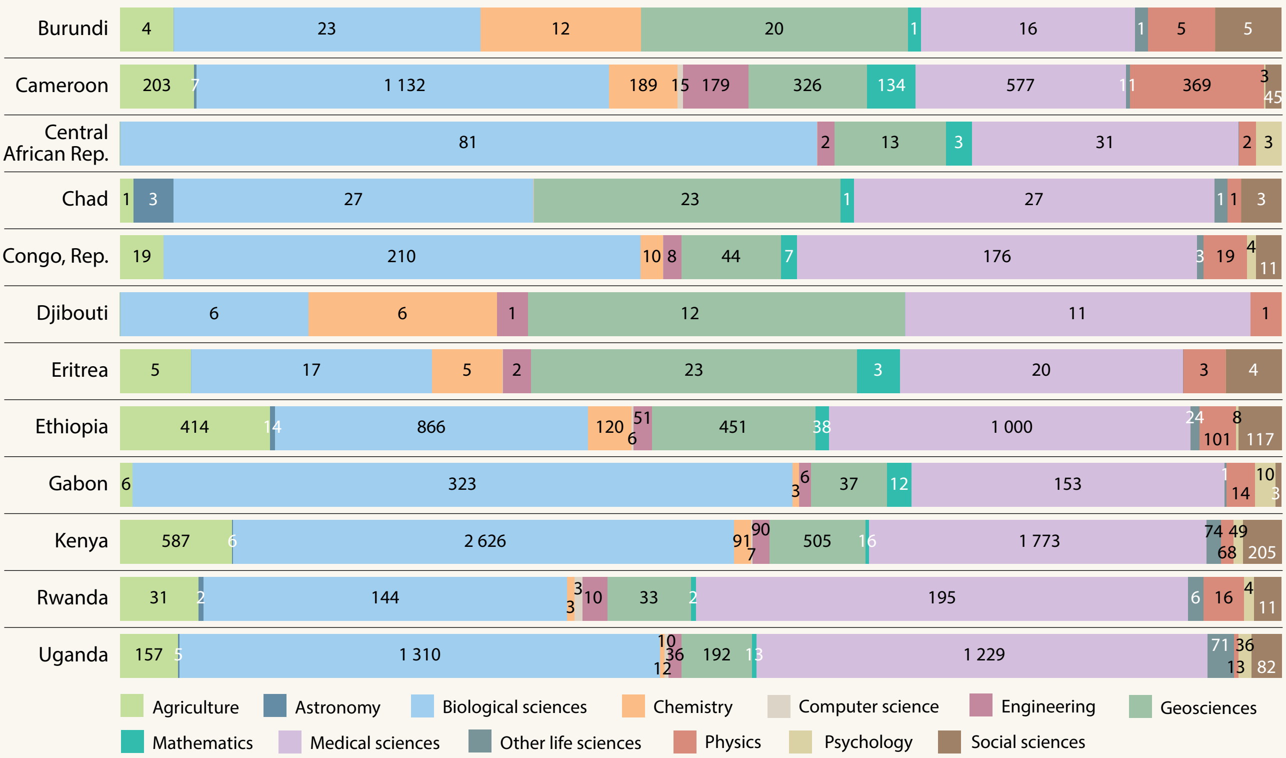
12.9%

Share of Ugandan papers among 10% most cited, 2008–2012; the G20 average is 10.2%



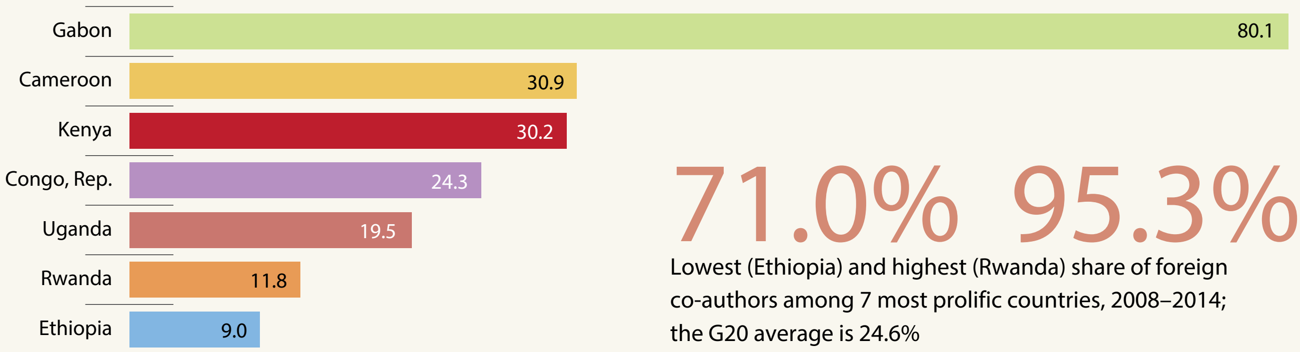
Life sciences dominate research in Central and East Africa

Cumulative totals by field for countries which recorded 15 articles or more in the Web of Science in 2014



Gabon was the most productive in 2014

Articles per million inhabitants for the most productive countries



71.0% 95.3%

Lowest (Ethiopia) and highest (Rwanda) share of foreign co-authors among 7 most prolific countries, 2008–2014; the G20 average is 24.6%

Scientists co-author most with partners outside Africa, some also with Kenya and South Africa

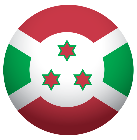
Main foreign partners of the 12 countries with the most publications, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Burundi	Belgium (38)	China (32)	USA (18)	Kenya (16)	UK (13)
Cameroon	France (1 153)	USA (528)	Germany (429)	South Africa (340)	UK (339)
Cent. African Rep.	France (103)	USA (32)	Cameroon (30)	Gabon (29)	Senegal (23)
Chad	France (66)	Switzerland (28)	Cameroon (20)	UK/USA (14)	
Congo, Rep.	France (191)	USA (152)	Belgium (132)	UK (75)	Switzerland (68)
Djibouti	France (31)	USA/UK (6)	Canada (5)	Spain (4)	
Eritrea	USA (24)	India (20)	Italy (18)	Netherlands (13)	UK (11)
Ethiopia	USA (776)	UK (538)	Germany (314)	India (306)	Belgium (280)
Gabon	France (334)	Germany (231)	USA (142)	UK (113)	Netherlands (98)
Kenya	USA (2 856)	UK (1 821)	South Africa (750)	Germany (665)	Netherlands (540)
Rwanda	USA (244)	Belgium (107)	Netherlands (86)	Kenya (83)	UK (82)
Uganda	USA (1 709)	UK (1 031)	Kenya (477)	South Africa (409)	Sweden (311)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

BURUNDI



An STI policy and the launch of R&D surveys
Burundi is a landlocked country with an economy dominated by subsistence agriculture. It has enjoyed a period of political stability and rapid economic development since the end of the civil war a decade ago. The World Bank's *Doing Business* report even named Burundi one of the world's top economic reformers in 2011–2013 for its efforts to streamline business, attract foreign investment and climb out of the league of the world's poorest countries (World Bank, 2013).

In 2010, the Department of Science, Technology and Research was created within the Ministry of Higher Education and Scientific Research to co-ordinate STI across the economy. Burundi then adopted a *National Policy on Science, Research and Technological Innovation* in 2011 (Tumushabe and Mugabe, 2012).

In 2011, Burundi published its *Vision 2025* document. The main targets to 2025 are to:

- achieve universal primary education;
- instigate good governance in a state of law, with regular elections;
- curb population growth from 2.5% to 2% per year to preserve gains in agricultural productivity and arable land, 90% of the population currently living off the land and more than half the population being under 17 years[5] of age;
- halve the current level of poverty (67% of the population) and ensure food security;
- improve the country's capacity to absorb the latest technology, in order to foster growth and competitivity;
- raise GDP per capita from US$ 137 in 2008 to US$ 720 and ensure annual economic growth of 10%;
- expand the urbanized population from 10% to 40% to preserve land;
- make environmental protection and the rational use of natural resources a priority.

The EAC Secretariat commissioned an assessment in 2011, in order to designate five centres of excellence in the community for EAC funding. The National Institute of Public Health in Burundi was one of the five; it provides training, diagnosis and research (Box 19.2).

5. The annual population growth rate in Burundi had accelerated to 3.1% by 2014, see Table 19.1.

Box 19.2: African centres of excellence in biomedical sciences

The EAC commissioned a study in 2011 which designated 19 centres of excellence from five EAC partner states. In October 2014, the 10th ordinary meeting of the EAC Sectorial Council of Ministers responsible for Health selected five of these centres for first-phase EAC funding, namely: the National Institute of Public Health (Burundi), Rift Valley Technical Training Institute (Kenya), University of Rwanda,* Uganda Industrial Research Institute and *Taasisi ya Sanaa na Utamaduni Bagamoyo* (Tanzania).

Complementing the EAC project, the African Development Bank (AfDB) approved bilateral loans in October 2014 amounting to US$ 98 million to finance the first phase of its own East Africa's Centres of Excellence for Skills and Tertiary Education in Biomedical Sciences programme.

The AfDB project will contribute to developing a highly skilled labour force in biomedical sciences to meet the EAC's immediate labour market needs and support implementation of EAC's 'free' labour market protocols. One potential area for growth is medical tourism.

The first phase of the AfDB project will support the creation of specialized centres of excellence in nephrology and urology in Kenya, cardiovascular medicine in Tanzania, biomedical engineering and e-health in Rwanda and oncology in Uganda. During the project's second phase, a centre of excellence will open in Burundi in nutritional sciences. The East Africa Kidney Institute will operate as part of the University of Nairobi and its teaching hospital, Kenyatta National Hospital. The other centres of excellence will be established at the University of Rwanda's College of Medicine and Health Sciences, the Uganda Cancer Institute and, in Tanzania, at Muhimbili University of Health and Allied Sciences. Some 140 master's and 10 PhD students will benefit from the programme, as well as 300 interns.

The centres of excellence will be expected to collaborate with internationally renowned establishments to develop quality curricula, joint research, promote inter-university exchanges and mentoring programmes and to give access to documentary resources.

*formerly the Kigali Institute of Science and Technology

Source: AfDB press release and personal communication; authors

Since joining the African Science, Technology and Innovation Indicators Initiative in August 2013, Burundi has been conducting national surveys of research and innovation to inform policy-making.

CAMEROON

Developing ICTs to catch up

In September 2007, the National Agency for Information and Communication Technologies published the *National Policy for the Development of Information and Communication Technologies*. Several programmes and projects were established under this policy for the post-2010 period, including (IST-Africa, 2012):

- a training programme for state personnel working in ICTs;
- measures to enhance the legal, regulatory and institutional framework governing ICTs, in order to provide a competitive environment for companies offering electronic communications services, catalyse innovation and promote service diversification and cost reduction; and
- an upgrade of the telecommunications network, such as fibre-optic cables.

The policy has spawned the following initiatives to promote the deployment of ICTs, among others (IST-Africa, 2012):

- the Ministry of Scientific Research and Innovation has issued an action plan for an information and knowledge society;
- the Ministry of Higher Education has implemented an ICT development programme in tertiary institutions;
- the Ministry of Secondary Education has built multimedia resource centres at secondary schools;
- mandatory ICT-related programmes have been introduced in primary and secondary schools; and
- the Prime Minister's Office has implemented a National Governance Programme.

The policy's implementation has nevertheless been hampered by a lack of financial resources, the inadequate synergy between the government and external partners and the weak state capacity for project management. Between 2007 and 2013, internet penetration spread only from 2.9% to 6.4% of the population. Despite this, two innovation hubs have been set up in recent years (Box 19.3).

The government is also supporting companies and fostering linkages between research and professional communities, in order to develop an indigenous ICT sector to realize the country's *Vision 2035.* Adopted in 2009, this planning document aims to turn Cameroon into a newly industrialized country by 2035. *Vision 2035* estimates that the informal sector represents 80–90% of the economy. Targets include:

- raising the share of manufacturing from 10% to 23% of GDP (it had almost reached 14% by 2013, see Figure 19.2);
- reducing the share of products from forestry, agriculture and aquaculture from 20.5% to 10% of exports by developing manufacturing;
- raising investment from 17% to 33% of GDP to drive technological development;
- expanding the number of tractors from 0.84 per 100 hectares to 1.2 per hectare;
- raising the proportion of doctors from 7 to 70 per 100 000 inhabitants; similar progress is to be realized among teachers, including in engineering fields: ICTs, civil engineering, agronomists, etc.;

Box 19.3: **ActivSpaces and CiHub: giving start-ups a head-start in Cameroon**

One important complementary scheme to government initiatives has been the creation of community technology and innovation hubs. A pioneer in this field is ActivSpaces; it provides facilities for web and mobile programmers, designers, researchers and entrepreneurs at co-working spaces in two Cameroonian cities, Douala and Buea. The hub aims to promote African-made technology, innovation and entrepreneurship, especially among youth and women.

Since 2015, ActivSpaces has been offering a six-month incubator or accelerator programme called Activation Bootcamp, which provides entrepreneurs with legal advice, mentorship, assistance in registering a start-up company and financial seeding, in return for a 5% share of equity in the venture. ActivSpaces also hosts various events, including a Demonstration Day to allow bootcamp participants to showcase their products and services.

Another innovation hub and incubator, the Cameroon Innovation Hub (CiHub), provides a launchpad for young tech entrepreneurs to develop start-ups based on internet and mobile technology to help address the country's social challenges. CiHub facilitates interactions among developers, entrepreneurs, companies and universities.

Source: compiled by authors

- raising the share of secondary and tertiary students specializing in S&T subjects from 5% to 30%;
- reducing the annual population growth rate from 2.8% to 2.0% through economic development and the emancipation of women, which will in turn encourage family planning;
- increasing access to drinking water from 50% to 75% of the population; and
- doubling energy consumption, mainly through the development of hydropower and gas.

CENTRAL AFRICAN REPUBLIC

The priority: getting child refugees back to school

The civil war since 2012 has severely disrupted the country's social fabric, generating an estimated 200 000 displaced persons. Since President Bozizé fled the country in 2013, first Michael Djotodia then Catherine Samba-Panza have served as interim president, Ms Samba-Panza since January 2014.

With a fragile ceasefire agreement in place since July 2014 and international peacekeepers on the ground, the country has begun rehabilitating infrastructure. The current transitional government and the Ministry of National Education and Higher Education and Scientific Research have been given the mandate of promoting STI for the recovery and sustainable development of the country. The ministry's top priority, however, is to resuscitate the education system from primary to university levels. The greatest challenge facing the education sector are the many school-age children living in refugee camps, compounded by the exodus of educated people, including teachers and professors.

CHAD

Plans to diversify mining

In recent years, Chad has suffered from flooding and drought, as well as conflict on its borders. Relations with Sudan improved after the signing of a non-aggression pact in 2010 but instability in Libya, Nigeria and Central African Republic since 2012 has forced it to raise its defence budget to handle a flood of refugees and counter growing cross-border threats, including that posed by the Boko Haram sect.

The economy has become dependent on oil over the past decade. This has produced erratic growth patterns as oil production has fluctuated. Chad hopes to double production in 2016, thanks to increased output from its Mangara and Badila fields, which are operated by the mining company Glencore Xstrata, and a new field managed by a subsidiary of the China National Petroleum Corporation (CNPC). According to the Minister of Finance, Kordje Bedoumra, Chad has commissioned consultancy firms from France and the Russian Federation to inventory potential mineral deposits of gold, nickel and uranium, in an effort to diversify the economy (Irish, 2014).

Chad is one of the world's least developed countries, ranking 183rd in the 2012 Human Development Index. Despite improvements in school attendance and access to clean drinking water (Tables 19.3 and 19.1), many Chadians still face severe deprivation and most Millennium Development Goals will not be met, according to the World Bank.

Chad has no specific STI policy. However, the law of 2006 mandates the Ministry of Higher Education and Scientific Research to co-ordinate STI.

COMOROS

Mobile phone technology fairly developed

The three small islands which make up Comoros group a population of 752 000, half of whom are under the age of 15. The economy is agrarian (37.1% of GDP), with manufacturing accounting for just 7% of national income. Although less than 7% of the population had access to internet in 2013, nearly one in two inhabitants (47%) subscribed to a mobile phone. Improved sanitation reaches only 17% of the population but 87% have access to clean water (Table 19.1).

In 2008, Comoros devoted a relatively large share of GDP to education (7.6%), one-sixth of which went to higher education (Table 19.2). One in ten (11%) young people attend the country's single public university, the University of Comoros, founded in 2003. By 2012, the university had a student roll of over 6 000, double that in 2007, but no PhD students (Table 19.4).

REPUBLIC OF CONGO

A push to modernize and industrialize

The Republic of Congo was the world's fourth fastest-growing economy in 2010, according to the World Bank. The government plans to turn Congo into an emerging economy by 2025, through *Vision 2025*. Adopted in 2011, this document foresees the diversification and modernization of the economy, which is heavily dependent on oil, and the development of secondary and tertiary education to provide the necessary skills base. To promote the rule of law, emphasis is being laid on strengthening participatory and inclusive democracy. There are programmes to develop physical (transportation) and virtual (ICTs) connections to domestic and foreign markets. Two key infrastructure projects are under way, the construction of a dam at Imboulou (120 MW) and the rehabilitation of the Congo Ocean railway.

Within a three-year agreement signed in December 2014, UNESCO is helping Congo to reinforce research and innovation by mapping Congo's STI ecosystem and developing instruments to ensure better policy implementation and a better status for researchers. One obstacle to innovation has been the lack of awareness of intellectual property rights, which has led to new knowledge being patented by better-informed competitors (Ezeanya, 2013). In 2004, Congo had requested UNESCO's support for the development of a national science and technology[6] policy. This led to the adoption of an action plan for 2010–2016. The new agreement reinforces existing programmes by focusing on modernization and industrialization.

To reflect the importance accorded to STI, the Ministry of Scientific Research and Technological Innovation has been separated from the Ministry of Higher Education, the Ministry of Primary and Secondary Education and the Ministry of Technical and Vocational Education. In January 2012, the Ministry of Scientific Research and Technological Innovation entered into a partnership with the Congolese company ISF Technologies to develop and integrate ICT solutions with business intelligence to optimize the performance of enterprises.

In Congo, university–industry ties tend to spring from initiatives by individual universities to support small enterprises. For example, the private non-profit ICAM School of Engineering in Pointe-Noire and Douala established a programme in November 2013 offering SMEs technical support.

DJIBOUTI

Education a priority

Expenditure on public education accounted for 4.5% of GDP in 2010. Schooling is free and seven out of ten children now attend primary school, although the ratio is higher for boys than for girls (Table 19.3). Until the founding of the University of Djibouti in 2006, students had to go abroad to study and could apply for a government sponsorship, a situation which fostered brain drain. In May 2014, the university launched an e-campus in the presence of the Minister of Higher Education and Research. The university plans to organize an international seminar on geohazards in early 2016. It is currently establishing an observatory to monitor climate change in East Africa, in collaboration with Yale University and the Massachusetts Institute of Technology in the USA.

Eight out of ten citizens work in the services sector, with manufacturing accounting for just 2.5% of GDP in 2007 (Figure 19.2). Djibouti's transformation into a modern hub is increasingly dependent on how well it can acquire technology from the global economy and adapt this to its level of development. FDI comes mainly from the Middle East and is high (19.6% of GDP in 2013) but tends to flow to the country's strategic port on the Red Sea. Investment projects with the potential for technology transfer and local capacity-building need strengthening. Greater statistical capability in STI indicators would also help the government to monitor improvements in this area.

Since joining the World Intellectual Property Organisation in 2002, Djibouti has enacted a law on the Protection of Copyright and Neighbouring Rights (2006) and a second law on the Protection of Industrial Property (2009).

EQUATORIAL GUINEA

International commitment, little domestic output

Founded in 1995, the National University of Equatorial Guinea is the country's main tertiary institution. It has faculties of agriculture, business, education, engineering, fisheries and medicine.

In 2012, President Obiang Nguema Mbasogo made funds available for the UNESCO–Equatorial Guinea International Prize for Research in the Life Sciences. In addition to rewarding research undertaken by individuals, institutions or other entities, the prize promotes the establishment and development of centres of excellence in the life sciences. The fact that the prize is international in character rather than aimed at citizens of Equatorial Guinea has attracted criticism within the country, which has high levels of poverty, despite being classified as a high-income country thanks to its oil-rent economy.

In February 2013, Equatorial Guinea applied to the African Union to host the African Observatory for Science, Technology and Innovation, the mandate of which is to collect data on the continent's STI capabilities. Having offered US$ 3.6 million and being the only applicant, Equatorial Guinea won the bid. Progress in establishing the facility has since been hampered by various administrative and political obstacles.

6. For details of UNESCO's work with the Republic of Congo since 2004, see the *UNESCO Science Report 2010*.

Despite these two high-profile international commitments, there is little information available on STI policy and implementation in Equatorial Guinea and, somewhat ironically, the country does not participate in STI data surveys. The Web of Science catalogued just 27 scientific articles from Equatorial Guinea between 2008 and 2014, placing Equatorial Guinea on a par with Comoros and Somalia for this indicator (Figure 19.8).

ERITREA

Urgent development challenges

Eritrea faces numerous development challenges. Just 0.9% of the population had access to internet in 2013 and 5.6% a mobile phone subscription (Table 19.1). There is also little access to improved sanitation (9%) and clean water (43%). To compound matters, the population is growing at one of the fastest rates in sub-Saharan Africa: 3.16% in 2014 (Table 19.1).

Two-thirds of the population worked in the services sector in 2009. With gold accounting for 88% of exports in 2012 (see Figure 18.1), there is an urgent need to diversify the economy to ensure sustainability and attract FDI, which contributed just 1.3% of GDP in 2013. Economic growth has been erratic, attaining 7.0% in 2012 but only 1.3% in 2013.

The Eritrea Institute of Technology is the main institution for higher studies in science, engineering and education. The facilities and capacity of the institute are continually being upgraded, thanks to largely external funding, although the Ministry of Education also contributes. The number of students graduating each year is rising steadily but from a low starting point. In 2010, just 2% of the 18–23 year-old cohort was enrolled in university and there were not as yet any PhD students (Tables 19.3 and 19.4). The number of Eritrean publications in the Web of Science dropped from 29 in 2006 to 22 in 2014 (Figure 19.8).

The National Science and Technology Council (NSTC), Eritrean Science and Technology Development Agency (ESTDA) and National Science and Technology Advisory Board were all established in 2002. The NSTC is responsible for the formulation, review and approval of policies but no specific S&T policy has been published since 2002, as far as can be ascertained. ESTDA is an autonomous corporate body with two main objectives: to promote and co-ordinate the application of S&T for development under the guidance of NSTC and to build the national capability for R&D.

ETHIOPIA

An ambitious plan for growth and transformation

For the past decade, Ethiopia has enjoyed some of the fastest economic growth in Africa among agrarian economies. The government is now focusing on modernization and industrialization to realize its ambition of turning Ethiopia into a middle-income economy by 2025.

The government recognizes that STI will be a prerequisite for realizing its *Growth and Transformation Plan for 2011–2015*. A government report has since mapped progress over the first two years of implementation (MoFED, 2013):

- improved crop and livestock productivity and soil and water preservation through research;
- greater generation and dissemination of geoscience data and more problem-solving research related to mining;
- the development of alternative construction technologies for road-building;
- the start of construction of a national railway network;
- sustainable technology transfer in medium and large-scale manufacturing industries to improve their export capacity, fostered through privatization and measures to attract foreign investors: by 2012, this sub-sector had registered growth of 18.6%, close to the target of 19.2%; there was 13.6% growth in value-added industrial products by 2012 but export earnings from textiles, leather goods, pharmaceuticals and agroprocessing have been disappointing, owing to low productivity and inadequate technological capability, a lack of inputs and other structural problems;
- the development of renewable energy, including through the Ashegoda and Adama-2 wind energy projects, the Great Ethiopian Renaissance Dam on the Blue Nile and the ongoing development of biofuel plants (jatropha, caster, etc.) on 2.53 million hectares of land;
- the development of a *Climate Resilient Green Economy Vision and Strategy*, as well as the enforcement of compliance with environmental laws and capacity-building in the mitigation of greenhouse gases;
- the number of tertiary-level students rose from 401 900 to 693 300 between 2009 and 2011; the target is for 40% of students to be women by 2015;
- a national survey of research and innovation in 2011–2012 found that 0.24% of GDP was being devoted to GERD, the same level as in 2009. The survey also inventoried 91 researchers per million population;

In parallel, the *National Science and Technology Policy* (2007) has been revised with UNESCO support, in order to take the following considerations into account:

- the transformation of the Ethiopian economy from a centralized to an open market economy, with concomitant political power decentralization;
- global advances in the understanding and application of STI and rapid socio-economic changes at national level;
- the imperative of developing a national STI capability, in order to seize the opportunities offered by global progress in scientific knowledge and technology; and
- the fragmented, unco-ordinated and uneconomic use of limited resources which characterized STI at the time.

The revised *National Science, Technology and Innovation Policy* has been operational since 2010. It seeks to 'build competitiveness through innovation.' Its strengths include upgrading the Science and Technology Commission to ministerial level with a consequential name change to Ministry of Science and Technology, advocating an annual government allocation of at least 1.5% of GDP for STI in all sectors and the creation of a centralized innovation fund for R&D resourced from a contribution of 1% of the annual profits realized in all productive and service sectors. As of mid-2015, neither the annual government allocation, nor the innovation fund were yet operational. The GERD/GDP ratio has risen, though, to 0.61% of GDP in 2013 (Figure 19.9), according to the UNESCO Institute for Statistics, which also reported a steep increase in the proportion of women researchers from 7.6% to 13.3% between 2010 and 2013.

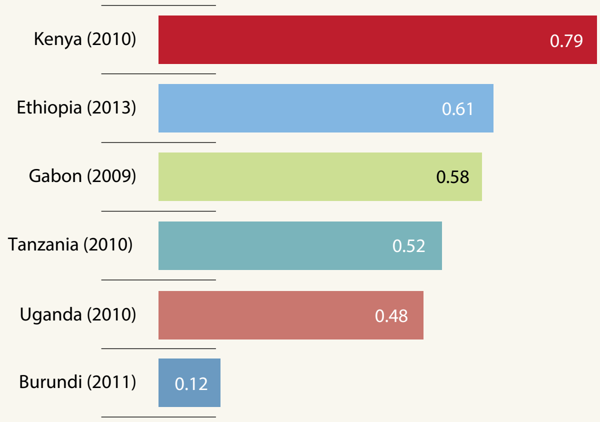
Two programmes stand out:

- the National Priority Technology Capability Programmes launched in 2010 in the areas of agricultural productivity improvement, industrial productivity and quality programmes, biotechnology, energy, construction and material technologies, electronics and microelectronics, ICTs, telecommunications and water technology; and
- the ongoing Engineering Capacity-Building Programme launched in 2005, which is jointly financed and implemented by the governments of Ethiopia and Germany within Ethiopian–German Development Co-operation. Priority sectors include textiles, construction, leather, agro-processing, pharmaceuticals/chemicals and metal.

In 2014, it was decided to place universities specializing in science and technology which have ties with industry under the new Ministry of Science and Technology to promote innovation in academia and stimulate technology-driven enterprises. The first two universities in Addis Ababa and Adama were transferred from the Ministry of Higher Education in 2014.

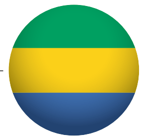
Figure 19.9: **GERD/GDP ratio in East and Central Africa, 2013, or closest year (%)**

Selected countries



Source: UNESCO Institute for Statistics

GABON



A plan to green Gabon by 2025

Gabon is one of the most stable countries in Africa. Despite being one of the continent's rare upper middle-income economies, it is characterized by considerable inequality in income distribution. There is also limited infrastructure, including in the transport, health, education and research sectors (World Bank, 2013).

The economy is dominated by oil but, with production starting to decline, the government has been implementing political and economic reforms since 2009 to transform Gabon into a developed country by 2025. This ambition is encapsulated in the government strategy, *Emerging Gabon: Strategic Plan to 2025*, which aims to set the country on the path to sustainable development, 'which is at the heart of the new executive's policy,[7]' according to the *Strategic Plan*. Adopted in 2012, it identifies two parallel challenges: the need to diversify an economy dominated by oil exports (84% in 2012, see Figure 18.1) and the imperative of reducing poverty and fostering equal opportunity.

The three pillars of the plan are:

- *Green Gabon:* to develop the country's natural resources in a sustainable manner, beginning with an inventory of 22 million ha of forest (85% of the land cover), 1 million ha of arable land, 13 national parks and 800 km of coastline;
- *Industry Gabon:* to develop local processing of raw materials and the export of high value-added products;

7. Gabon's President Ali Bongo Ondimba took office in October 2009.

- *Services Gabon:* to foster quality education and training, in order to turn Gabon into a regional leader in financial services, ICTs, green growth, tertiary education and health.

The plan foresees the adoption of a *National Climate Plan* to limit Gabon's greenhouse gas emissions and forge an adaptation strategy. The share of hydropower in Gabon's electricity matrix is to progress from 40% in 2010 to 80% by 2020. In parallel, inefficient thermal power stations are to be replaced with clean ones to bring the share of clean energy to 100%. By 2030, Gabon plans to export 3 000 MW of hydropower to its neighbours. Efforts will also be made to improve energy efficiency and reduce pollution in such areas as construction and transportation.

This new paradigm is to be ensconced in a law on sustainable development which will create a fund compensating the negative effects of development. Moreover, in conformity with the *Gaborone Declaration* (see Box 20.1), natural capital is to be integrated into the national accounting system.

Quality education a priority

Quality education is another priority of the *Strategic Plan* to 2025. Four technical secondary schools offering 1 000 places are to be established to raise the proportion of pupils benefiting from this education from 8% to 20% and thereby provide key economic sectors such as the wood, forestry, mining,[8] metallurgy and tourism industries with skilled personnel.

In order to adapt university curricula to market needs, existing universities will be modernized and a *Cité verte de l'éducation et du savoir* (Green City of Education and Knowledge) will be created in the heart of the country in Booué. Constructed using green materials and running on green energy, this complex will group a campus, research centres and modern housing. Foreign universities will be encouraged to set up campuses on site. A research fund will be created for academic projects selected on a competitive basis and an information technology park will be set up in partnership with the National Agency for Digital Infrastructure and Frequencies.

All primary and secondary schools are to be equipped with a multimedia room and a mechanism will be put in place to enable all teachers and university students to acquire a computer.

In parallel, the plan foresees a broad administrative and legal reform to improve efficiency and foster the rule of law. A number of new bodies will be established to foster quality education, including the Council for Education, Training and Research, which will be responsible for evaluating the implementation of the government's education policy.

Steps taken to implement the *Strategic Plan*

Since 2011, the government has taken a number of steps to implement *Emerging Gabon: Strategic Plan to 2025*, including:

- the creation of a Research Unit on Tuberculosis at the Albert Schweitzer Hospital in Lambaréné in February 2011, in response to the growing prevalence of tuberculosis;
- the creation of a joint Centre for Environmental Research by Gabon and the University of Oregon (USA) in June 2011, with a focus on the mitigation of, and adaptation to, climate change and environmental governance, including the development of ecotourism;
- the construction of a School of Mining and Metallurgy in Moanda in October 2012 to produce more scientists and engineers in these areas;
- the opening of a digital campus at the School of Water Affairs and Forestry in February 2013 to produce more engineers;
- the creation of three new vocational training centres in June 2013;
- the official presentation of the *National Climate Plan* to the president in November 2013 by the National Council on Climate Change, a body created by presidential decree in April 2010;
- the establishment of a Ministry of Higher Education and Scientific Research in April 2014; and
- the adoption of the law on sustainable development in August 2014; this law has raised some concerns in civil society as to whether it will protect the territorial rights of third parties, particularly those of local and indigenous communities (Malouna, 2015).

The government has recently entered into two public–private partnerships. In December 2012, it established a 'fun' approach to learning about HIV which targets youth, called Gaming for HIV Prevention, in partnership with Shell Gabon. In February 2013, the government also partnered with Ireland Blyth Limited to develop the Gabonese seafood and maritime industries.

8. In 2010, Gabon attracted over US$ 4 billion for the wood, agriculture and infrastructure sectors, according to the government.

KENYA

A game-changing act?

STI policy in Kenya has been given a major boost by the Science, Technology and Innovation Act passed in 2013. The act contributes to the realization of *Kenya Vision 2030*, which foresees the country's transformation into a middle-income economy with a skilled labour force between 2008 and 2030. Kenya already hosts[9] several hubs for training and research in life sciences, including the Biosciences Eastern and Central Africa Network (Box 19.1) and the International Centre for Insect Physiology and Ecology. In line with *Vision 2030*, Kenya is participating in the AfDB's East Africa's Centres of Excellence for Skills and Tertiary Education in Biomedical Sciences programme (Box 19.2).

Flagship projects within *Vision 2030* include the following:

- Five industrial parks are being established for SMEs in key urban centres, the majority in agro-processing.
- The Nairobi Industrial and Technology Park is being developed within a joint venture with Jomo Kenyatta University of Agriculture and Technology.
- Konza Technology City is under construction in Nairobi (Box 19.4).
- Geothermal energy is being developed in the Rift Valley, within a programme to increase energy generation to 23 000 MW that is mobilizing private capital for the development of renewable energy (Box 19.5).
- Construction of Africa's largest wind farm began in 2014, within the Lake Turkana Wind Power Project;
- In recognition of the economic potential of ICTs, the government announced in December 2013 that it would be establishing technology incubation hubs in all 47 counties.

Under the Science, Technology and Innovation Act of 2013, the Ministry of Education, Science and Technology is attributed responsibility for formulating, promoting and implementing policies and strategies in higher education, STI in general and R&D in particular, as well as technical, industrial, vocational and entrepreneurship training.

The act established a National Commission for Science, Technology and Innovation, a regulatory and advisory body that is also responsible for quality assurance. Its specific functions include:

- developing priority areas for STI; co-ordinating the implementation and financing of policies with other institutional bodies, including local governments, the new National Innovation Agency and the new National Research Fund (see overleaf);
- providing accreditation for research institutes;
- fostering private-sector involvement in R&D; and
- undertaking annual reviews of scientific research systems.

The act further empowered the National Commission for Science, Technology and Innovation to establish advisory research committees to counsel the commission on specific programmes and projects and maintain a database of these and to foster R&D and education in relevant areas, in particular. The act also establishes a requirement for any person wishing to engage in R&D to obtain a government license.

9. Nairobi is also home to the African Network of Scientific and Technological Institutions (ANSTI), an NGO hosted by UNESCO since its inception in 1980. ANSTI awards PhD and master's scholarships and travel grants. Since 2010, ANSTI has awarded 45 L'Oréal-UNESCO Fellowships for Women in Science to foster research and innovation.

Box 19.4: **Konza Technology City, Kenya's 'Silicon Savannah'**

Konza Technology City was originally designed as a technology park centred on business process outsourcing and information technology-enabled services. The Kenyan government contracted the International Finance Corporation to conduct an initial feasibility study in 2009. However, while the study was being conducted, the consulting design partners recommended that the project be expanded into a technology city. The Kenyan government agreed and has branded Konza the 'Silicon Savannah'.

A 5 000-acre site located some 60 km from Nairobi was procured in 2009 and the new greenfield investment (see glossary, p. 738) commenced. The financing arrangement is based on a public–private partnership model, whereby the government provides basic infrastructure and supporting policy and regulatory frameworks, leaving private investors to build and operate the industrial development. Ultimately, Konza should include a university campus, residential accommodation, hotels, schools, hospitals and research facilities.

Development of the techno-city is being directed by the Konza Technopolis Development Authority, which has authority over marketing, the subleasing of land, guiding real estate development, managing funding from public and private sources and liaising with local authorities to ensure quality services. Construction of Konza Technology City began in early 2013 and is expected to take 20 years. It is hoped to create 20 000 jobs in information technology by 2015 and 200 000 by 2030.

Source: www.konzacity.go.ke; BBC (2013)

The Kenya National Innovation Agency was established under the act to develop and manage the national innovation system. It has been tasked *inter alia* with the following: institutionalizing linkages between relevant stakeholders, including universities, research institutions, the private sector and government:

- setting up science and innovation parks;
- promoting a culture of innovation;
- maintaining relevant standards and databases; and
- disseminating scientific knowledge.

The act also created the National Research Fund and made provisions for the fund to receive 2% of Kenya's GDP each financial year. This substantial commitment of funds should enable Kenya to reach its target of raising GERD from 0.79% of GDP in 2010 to 2% by 2014.

Kenya reviewed its *Science, Technology and Innovation Policy* in 2012 but the revised policy is still before parliament. The draft is nonetheless serving as a reference document for the Ministry of Education, Science and Technology.

Towards a digital Kenya

In August 2013, the Ministry of Information, Communication and Technology established a state-owned corporation named the Information and Communication Technology Authority. Its functions include centralized management of all government ICT functions; maintenance of ICT standards across government; and the promotion of ICT literacy, capacity, innovation and enterprise, in accordance with the *Kenya National ICT Master Plan: Towards a Digital Kenya*, which runs from 2014 to 2018.

In the past few years, there has been an explosion in ICT activity in Kenya, often centred on innovation hubs. One pioneer is iHub, set up in Nairobi in 2010 by an independent technologist named Erik Hersman to provide an open space for the technology community, including young tech entrepreneurs, programmers, investors and technology companies. iHub has forged relationships with several multinational corporations, including Google, Nokia and Samsung, as well as with the Kenyan government's ICT Board (Hersman, 2012).

Another innovation hub is @iLabAfrica, established in January 2011 as a research centre within the Faculty of Information Technology at Strathmore University, a private establishment based in Nairobi. It stimulates research, innovation and entrepreneurship in ICTs.

A related development in Kenya is the formation of innovation incubation programmes. A prominent example is NaiLab, an incubator for start-up ICT businesses which offers a three-to-six-month programme in entrepreneurship training. NaiLab started out as a private company in 2011, in collaboration with the crowdfunding platform 1%CLUB and consultancy firm Accenture. In January 2013, the Kenyan government formed a partnership with NaiLab to launch a US$ 1.6 million, three-year technology incubation programme to support the country's burgeoning technology start-up

Box 19.5: Geothermal energy for Kenya's development

Just one in five Kenyans has access to electricity and demand is rising (Table 19.1). Almost half of electricity comes from hydropower but the growing frequency of drought is causing water and power shortages which affect all sectors of the Kenyan economy. As a stop-gap measure, the government has engaged private energy companies which import fossil fuels such as coal and diesel, a costly option which also causes considerable air pollution.

Vision 2030 (2008) has identified energy as being a pillar of the country's development strategy. *Vision 2030* is being implemented through successive five-year medium-term plans. It sets an ambitious goal of increasing the capacity of the national power supply from 1 500 MW at present to about 21 000 MW by 2030.

To address the energy challenge while maintaining a low carbon footprint, Kenya plans to develop its geothermal fields in the Rift Valley. These fields have been inadequately tapped until now, despite their potential to produce an estimated 14 000 MW. Current installed geothermal capacity corresponds to just 1.5% of this potential.

The Geothermal Development Company (GDC) was formed in 2009 under the Energy Act (2006) to implement the *National Energy Policy*. The GDC is a government body which cushions investors from the high capital investment risks associated with drilling geothermal wells. The GDC is expected to drill as many as 1 400 wells to explore steam prospects and make productive wells available to successful bidding investors from both public and private power companies.

In the fiscal year budget for 2012–2013, the Kenyan government allocated US$ 340 million to the exploration and development of geothermal energy and coal. Of this amount, just US$ 20 million went to the GDC.

Source: WWAP (2014)

sector (Nsehe, 2013). These funds will enable NaiLab to broaden its geographical scope to other Kenyan cities and towns, helping start-ups to obtain information, capital and business contacts.

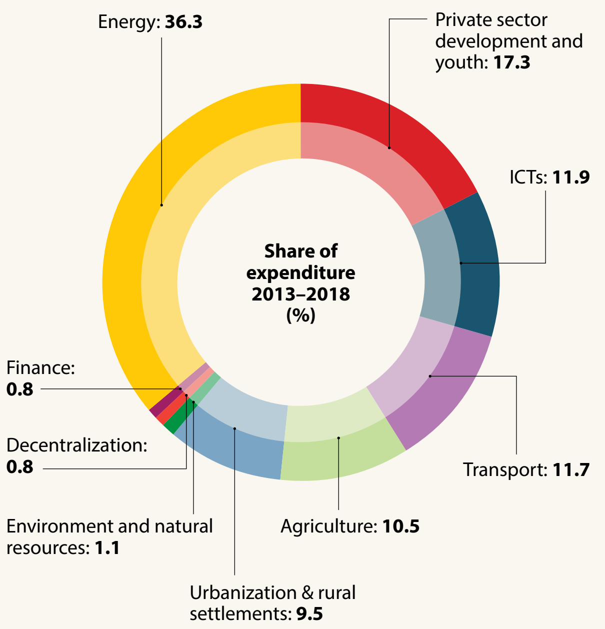
Nairobi is also home to m:Lab East Africa, which provides a platform for mobile entrepreneurship, business incubation, developer-training and application-testing.

RWANDA

Infrastructure, energy and 'green' innovation a priority

In a context of rapid economic and demographic growth, STI holds one of the keys to Rwanda's sustainable development. This conviction is embodied in *Rwanda's Vision 2020* (2000) for becoming a middle-income country by 2020 and in its *National Policy on Science, Technology and Innovation*, published in October 2005 with support from UNESCO and the United Nations University. The priority given to STI is also reflected in Rwanda's *First Economic Development for Poverty Reduction Strategy*, 2007–2012. If STI is not an explicit priority in the *Second Economic Development for Poverty Reduction Strategy*, 2013–2018, it is implicit in the priority given in the document to ICTs, energy and 'green' innovation (Figure 19.10), as well as in the proposal to create a Climate Change and Environment Innovation Centre. The five priorities are to:

Figure 19.10: **Breakdown of priority areas for *Rwanda's Economic Transformation* to 2018**



Source: Government of Rwanda (2013) *Second Economic Development for Poverty Reduction Strategy*, 2013–2018

- invest in hard and soft infrastructure to meet the energy demand of the private sector; in line with the *Energy Policy* (2012), the procurement process will be made more transparent and competitive; public finance will be used to 'de-risk' electricity generation projects for the private sector, in order to attract a wider range of investors on better terms; an energy development fund will be established with donor support to finance feasibility studies on geothermal, peat and methane resources and hydropower; in addition, the Kigali Economic Zone will also be finalized with an associated technopole;
- increase access to public goods and resources in priority economic sectors by building a new international airport, expanding the national airline, Rwandair, and finalizing plans for the establishment of a railway connection; a strategic focus on exports and re-exports to Burundi and eastern Democratic Republic of Congo; investment in hard and soft infrastructure to accelerate growth in the tourism and commodity sectors and expand exports in manufacturing and agro-processing;
- strengthen the investment process by targeting large foreign investors in priority economic sectors, increasing long-term savings and thereby raising the amount of credit available to the private sector to 30% of GDP by 2018, as well as by strengthening the private sector through tax and regulatory reform;
- facilitate and manage urbanization, including the promotion of affordable housing;
- pursue a 'green economy' approach to economic transformation, with a focus on green urbanization and green innovation in public and private industry; a pilot green city is being launched by 2018 to 'test and promote a new approach to urbanization' that employs various technologies to create sustainable cities; in parallel, a green accounting framework is being put in place to assess the economic benefits of environmental protection.

There is no dedicated ministry for science and technology in Rwanda but, in 2009, the Directorate-General of Science, Technology and Research was established under the Ministry of Education to implement the *National Policy on Science, Technology and Innovation*. In 2012, the government officially launched the National Commission for Science and Technology (NCST). The NCST has been strategically positioned in the Prime Minister's Office to serve as an advisory body on matters related to STI across all economic sectors. It became operational in 2014.

The National Industrial Research and Development Agency (NIRDA) was established in June 2013, in line with the *National Industrial Policy* of April 2011. The main mission of this research body is to produce home-grown technological and industrial solutions to meet national and regional market needs.

Plans to become an African ICT hub

In the past five years, Rwanda has put infrastructure in place to enable it to become an ICT hub in Africa. This infrastructure includes the Kigali Metropolitan Network, a fibre optic network linking all government institutions with a high-capacity national backbone connecting the whole country. The national backbone also links Rwanda with neighbouring countries, including Uganda and Tanzania, and through them to the submarine cables SEACOM and EASSy.

The Information Technology Innovation Centre (kLab) was established in 2012. It has been conceived as a place where young software developers and recent university graduates from computer science and engineering programmes can come to work on their entrepreneurial projects. This technology incubator partners with universities, research centres and private companies to provide mentoring for innovative start-ups, helping them to acquire business skills and transfer technology. Since its inception, kLab has been supported by the Rwanda Development Board.

In 2012, Rwanda constructed a state-of-the-art data-hosting facility for public and private institutions, the National Data Centre. A Health Management Information System (TRACnet) has also been deployed since 2005 to increase the efficiency of Rwanda's HIV and AIDS programme and enhance the quality of patient care country-wide.

The government is currently developing an ICT park in Kigali, in partnership with Carnegie Mellon University and the AfDB, for a total investment of US$ 150 million. The park will support growth of the following clusters: energy; internet, multimedia and mobile telecommunications; knowledge; e-government; finance; and ICT services and exports.

Towards more scientists and engineers with better skills

In 2012, Carnegie Mellon University in Rwanda was established as a regional centre of excellence in ICTs. It is the first US research institution to offer degrees in Africa through an in-country presence. The government decided to partner with this leading private research university in the USA, in order to produce ICT engineers and leaders who understand the balance between technology, business and innovation to meet the needs of industry.

Rwanda had only 11.8 articles per million inhabitants indexed in the Web of Science in 2014 (Figure 19.8). In September 2013, parliament passed a law establishing the University of Rwanda as an autonomous academic research institution. This large university is the product of the merger of seven public institutions of higher learning into a single university. The philosophy behind creating the University of Rwanda was to produce better-trained graduates and to strengthen the research capacity of Rwanda's higher education system. The University of Rwanda has already entered into an agreement with the Swedish International Development Agency to produce 1 500 PhDs between 2012 and 2022.

In October 2013, UNESCO's Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste (Italy) established a branch in Rwanda. Hosted by the College of Science and Technology at the University of Rwanda, ICTP Rwanda aims to increase the number of scientists graduating at master's and PhD levels in strategic areas of science, technology, engineering and mathematics. In 2012, the government adopted a policy of allocating 70% of university scholarships to students enrolled in S&T fields to increase the number of graduates. Moreover, through the Presidential Scholarship Programme established in 2006, pupils from science streams who excel in their secondary schooling get the chance to study in the USA in science or engineering. In 2013, two-thirds of graduates at bachelor level

Table 19.6: **University graduates in Rwanda, 2012/2013**

	Bachelor's		Master's		PhD	
	Male	Female	Male	Female	Male	Female
Education	763	409	3	3	0	0
Humanities and arts	187	60	0	0	1	0
Social sciences, business and law	3 339	3 590	261	204	0	0
Science	364	204	1	6	0	0
Engineering, manufacturing and construction	462	205	39	11	0	0
Agriculture	369	196	0	0	0	0
Health and welfare	125	211	5	4	0	0
Services	171	292	0	0	0	0
TOTAL	**5 780**	**5 167**	**309**	**228**	**1**	**0**

Source: Government of Rwanda

obtained their degree in social sciences, business and law, compared to 19% in S&T fields: 6% in engineering, 5% each in science and agriculture and 3% in health and welfare. Among graduates in S&T fields, engineering students were the most likely to enrol in a master's programme (Table 19.6).

Schemes to boost innovation and a green economy

The Rwanda Innovation Endowment Fund was established in 2012 by the Ministry of Education, in partnership with UNECA. The fund supports R&D to develop innovative market-oriented products and processes in three priority sectors of the economy: manufacturing, agriculture and ICTs. For the initial phase, seed funding of US$ 650 000 was provided: US$ 500 000 by the government and the remainder by UNECA. The first call for project proposals drew 370 applications, leading to the selection of just eight projects, which each received about US$ 50 000 in May 2013. After this proof of concept, it was decided to conduct a second round which is expected to fund ten inventions by March 2015.

In January 2013, the Ministry of Education established the Knowledge Transfer Partnership programme, in collaboration with the AfDB to foster industrial development. So far, the programme has sponsored five partnerships between private companies and the University of Rwanda's two Colleges of Science and Technology and Agriculture and Veterinary Medicine. The company contributes its idea for product or service development and the university provides the appropriate expertise.

In September 2008, Rwanda banned plastic bags. The law prohibits the manufacture, usage, importation and sale of polythene bags in Rwanda. These have been replaced by biodegradable bags made from materials such as cotton, banana and papyrus.

In parallel, the government introduced a National Fund for Environment and Climate Change in Rwanda (FONERWA), which acts as a cross-sectorial financing mechanism to further Rwanda's objectives of green and resilient growth within the *National Green Growth and Climate Resilience Strategy*. For instance, FONERWA is involved in identifying funding for the pilot 'green city' to be launched by 2018.

FONERWA's most recent (sixth) call for proposals resulted in 14 projects receiving funding; these had been put forward by private companies, NGOs, Rwandan districts and the Ministry of Infrastructure. The projects include the provision of solar power to off-the-grid communities, the construction of microhydropower plants, rainwater harvesting and re-use and gardening for urban poor in developed marshlands of Kigali.

SOMALIA

A first innovation hub

Somalia is in the process of state- and peacebuilding. In the run-up to elections in 2016, it is developing a constitution with key provisions on power- and resource-sharing. The government is also pursuing the development of federalism by building the capacity of interim regional administrations and establishing such bodies where none exists. The government has also recently applied to become a member of the EAC.

The Al-Shabaab group continues to terrorize the population in parts of the country under its control. About 730 000 Somalis face acute food insecurity, the vast majority of them internally displaced people. Some 203 000 children require emergency nutrition, mainly due to lack of access to clean water, sanitation infrastructure and better hygiene, according to the United Nations Humanitarian Co-ordinator for Somalia, Philippe Lazzarini, in January 2015.

Agriculture is the mainstay of Somalia's largely informal economy, accounting for about 60% of GDP and employing two-thirds of the labour force. The country continues to rely heavily on international aid and remittances, as well as imports of food, fuel, construction materials and manufactured goods. The more stable parts of the country can nevertheless boast of a vibrant private sector, including as concerns the provision of such vital services as finance, water and electricity.

Somalia's first innovation hub was established in 2012. Somaliland provides mobile and internet services and fosters social enterprise incubation and social and disruptive innovation (see glossary, p. 738), accompanied by training. The hub was set up by Reconstructed Living Lab, a registered social enterprise based in South Africa, with its partner Extended Bits and funding from the Indigo Trust, a UK-based foundation.

SOUTH SUDAN

Priorities: raising education and R&D spending

The world's youngest nation and Africa's 55th country, South Sudan gained independence after seceding from Sudan in July 2011. Its economy is highly dependent on oil, which generates about 98% of government revenue. Part of this revenue goes towards paying Sudan for the right to use its pipelines to transport oil to the sea for export.

With the economy suffering from a dearth of skilled human resources in all the key sectors, education is a government priority. The Education Act (2012) states that 'primary education shall be free and compulsory to all citizens in South

Sudan without discrimination.' The government's education plan is placing emphasis on teachers and on raising public expenditure on education to improve access and learning outcomes. South Sudan has the second-highest rate of population growth in sub-Saharan Africa after Niger (3.84%, see Table 19.1) and there is a big discrepancy in access to primary education: whereas there is universal primary education for boys, the gross enrolment ratio for girls was just 68% in 2011.

Tertiary education in South Sudan is provided by five government-sponsored universities and more than 35 private tertiary institutions. An estimated 20 000 students were enrolled in the country's universities in 2011, according to data from various universities; these data also indicate that enrolment is higher in social sciences and humanities than in S&T fields. The S&T-based faculties are particularly affected by a shortage of teaching staff.

The Ministry of Higher Education, Science and Technology has six directorates, including the Directorate of Technical and Technological Innovation (DTTI). The latter is a programme unit supporting the modernization of South Sudan through investment in technical education and the generation and transfer of technology. DTTI is composed of two departments covering technology and entrepreneurship. Whereas the former is responsible for developing technology policies and managing S&T-based institutions and programmes, the latter is responsible for establishing and managing institutions offering technical, vocational and entrepreneurial training and for laying the foundations for cottage industries. There are no official government statistics available on R&D but the government has expressed the intention of raising spending on research, with emphasis on applied sciences to improve living standards.

UGANDA

Sustainability at the heart of STI policy

The overarching arm of the *National Science, Technology and Innovation Policy* (2009) is to 'strengthen national capability to generate, transfer and apply scientific knowledge, skills and technologies that ensure sustainable utilisation of natural resources for the realisation of Uganda's development objectives.'

The policy precedes *Uganda Vision 2040*, which was launched in April 2013 to transform 'Ugandan society from a peasant to a modern and prosperous country within 30 years,' in the words of the Cabinet. *Uganda Vision 2040* vows to strengthen the private sector, improve education and training, modernize infrastructure and the underdeveloped services and agriculture sectors, foster industrialization and promote good governance, among other goals. Potential areas for economic development include oil and gas, tourism, minerals and ICTs.

A Millennium Science Initiative and innovation fund

The National Council for Science and Technology (NCST) falls under the Ministry of Finance, Planning and Economic Development. The council's strategic objectives include: the rationalization of S&T policy to boost technological innovation; enhancing the national system of research, intellectual property, product development and technology transfer; strengthening public acceptance of science and technology; and upgrading institutional research capacity.

In 2007, the NCST launched the Millennium Science Initiative (2007–2013), which was co-financed by the World Bank. At a time when the economy's formal sector was expanding rapidly and real investment was rising sharply, the NCST considered that continued economic progress would require more and better use of knowledge and more and better qualified human resources for science and technology.[10] The NCST identified the following shortcomings in higher education:

- Very few science degree programmes exist; enrolment in basic sciences is negligible. Laboratories are generally scarce, under-equipped and obsolete.
- Very limited funding exists for capital or recurrent expenses for S&T training; almost all research funding comes from external (donor) sources, making it unsustainable and difficult to ensure a national research for development-driven agenda.
- Despite the burgeoning enrolment, very little systematic attention is being paid to the development of domestic graduate education. Fewer than 500 professors in the entire country have PhDs and fewer than 10 new PhDs are awarded annually in sciences and engineering.
- Fee policies and lack of adequate S&T infrastructure encourage the expansion of undergraduate programmes in arts and humanities, resulting in a dwindling intake for S&T courses and a general lack of interest in, and focus on, S&T.
- The universities and the general tertiary system, be it public or private, lack strategies to improve conditions for research.

To correct these shortcomings, the Millennium Science Initiative incorporated the following components:

- A funding facility provided competitive grants through three windows: top-end research involving both senior researchers and graduate students; the creation of undergraduate programmes in basic science and engineering; and, thirdly, support for co-operation with the private sector, which consisted in company internships for students and grants for technology platforms through

10. see: www.uncst.go.ug/epublications/msi_pip/intro.htm which firms and researchers could collaborate on solving problems of direct interest to industry.

- An Outreach Programme proposed a series of school visits by top scientists and researchers to change negative perceptions that deterred Ugandans from pursuing careers in science. A National Science Week was also established. In parallel, this second component sought to strengthen the institutional capacity of the NCST and Uganda Industrial Research Institute and, more generally, to improve policy implementation, evaluation and monitoring.

In July 2010, the Presidential Initiative on Science and Technology offered a further boost by creating a fund to foster innovation at Makerere University over the next five years (Box 19.6).

Thriving innovation hubs

The Uganda Investment Authority is a parastatal agency that works in conjunction with the government to facilitate private sector investment. One of the authority's most flourishing sectors is ICTs. This sector has seen major investment in recent years to develop Uganda's backbone infrastructure network, which is comprised of fibre-optic cables and related equipment, as well as mobile broadband infrastructure.

Uganda has a thriving innovation hub named Hive Colab, which was launched in 2010 by AfriLabs and is headed by Barbara Birungi. It serves as a collaborative space to facilitate interaction among technology entrepreneurs, web and mobile app developers, designers, investors, venture capitalists and donors. Hive Colab provides facilities, support and advice to members to help them launch successful start-up enterprises. The hub offers a virtual incubation platform that is intended to assist entrepreneurial activity, particularly in rural areas. Its three programme focus areas are ICTs and mobile technologies, climate technologies and agribusiness innovation.

Another incubator, the Consortium for enhancing University Responsiveness to Agribusiness Development Limited (CURAD), is a public–private partnership which targets young innovators in the agribusiness sector with the goal of generating new enterprises and employment. This non-profit company was launched in May 2014 and is based at Makerere University.

In September 2013, the government launched a Business Process Outsourcing Incubation Centre at the Uganda Bureau of Statistics House (Biztech Africa, 2013). The facility can accommodate 250 agents and is run by three private companies. The Government of Uganda has targeted this industry to address youth unemployment and stimulate investment in information-technology-enabled services Business incubation and STI research are also promoted by the Uganda Industrial Research Institute.

Two annual prizes have also incentivized innovation in Uganda. Each year since 2012, Orange Uganda, a division

Box 19.6: The Presidential Innovations Fund in Uganda

When President Museveni visited Makerere University in December 2009, he noticed that many undergraduate students had produced interesting prototypes of machines and implements and that PhD students and senior researchers were working on inventions with potential for transforming rural Ugandan society but that innovation was being held back by the lack of modern research and teaching laboratories.

After the visit, he decided to create a Presidential Innovations Fund endowed with UGX 25 billion (*circa* US$ 8.5 million) over five years to support innovation-related projects at the university's College of Engineering, Art, Design and Technology.

The fund became operational in July 2010. It covered the cost of modernizing laboratories and the implementation of ten projects at the university. It also financed undergraduate science and engineering programmes, academia–private sector partnerships, student internships, science policy formulation and science popularization in schools and communities.

By 2014, the projects had developed:

- an academic records management system;
- more than 30 internet laboratories (ilabs) in the Department of Electrical and Computer Engineering;
- a business incubator, the Centre for Technology Design and Development;
- a Centre for Renewable Energy and Energy Conservation;
- more than 30 innovation clusters for metal, salt, coffee, milk, pineapple, etc.;
- appropriate irrigation;
- a vehicle design project (the Kiira EV car), which evolved into the Centre for Research in Transportation Technologies;
- makapads, the only sanitary wear for women in Africa made from natural materials (papyrus and paper), including for maternity use;
- a Community Wireless Resource Centre.

Source: http://cedat.mak.ac.ug/research/presidential-initiative-project.html of France Telecom, has sponsored the Community Innovations Awards, a competition for mobile apps that encourages university students to innovate in the areas of agriculture, health and education. Since 2010, the Uganda Communications Commission has also organized the Annual Communications Innovation Awards, which reward excellence in ICT innovation that contributes to national development goals. The prizes are awarded in several categories, including digital content, ICT for development, service excellence, business excellence and young ICT innovators.

A rise in researchers and R&D spending

Uganda provides quite detailed data on research, making it possible to monitor progress. R&D funding climbed between 2008 and 2010 from 0.33% to 0.48% of GDP. The business enterprise sector's share of R&D funding progressed from 4.3% to 13.7% over this period and spending on engineering from 9.8% to 12.2%, to the detriment of agricultural R&D, which appears to have shrunk from 53.6% to 16.7% of total spending, according to the UNESCO Institute for Statistics.

The number of researchers has climbed steadily over the past decade, even doubling between 2008 and 2010 in head counts from 1 387 to 2 823, according to the UNESCO Institute for Statistics. This represents a leap from 44 to 83 researchers per million inhabitants. One in four researchers is a woman (Figure 19.3).

Enrolment in higher education rose from 93 000 to 140 000 between 2006 and 2011, in a context of strong population growth of 3.3% per year. In 2011, 4.4% of young Ugandans were enrolled at university (Tables 19.1, 19.3 and 19.4).

The number of scientific publications tripled between 2005 and 2014 but research remains focused on life sciences (Figure 19.8). In 2014, the Uganda Industrial Research Institute was selected for a programme which is developing centres of excellence in biomedical sciences (Box 19.2). Interestingly, Kenya and South Africa count among Uganda's top five research partners (Figure 19.8).

CONCLUSION

Social and environmental innovation emerging priorities

The period since 2009 has witnessed a considerable gain in interest for STI in East and Central Africa. Most countries have based their long-term planning ('vision') documents on harnessing STI to development. Most governments are perfectly cognizant of the need to seize the opportunity of sustained growth to modernize and industrialize, in order to participate effectively in a rapidly evolving world economy and ensure sustainability. They know that infrastructure development, better health care, food, water and energy security and economic diversification will require a critical mass of scientists, engineers and medical staff who are currently in short supply. These planning documents tend to reflect a common vision for the future: a prosperous middle-income country (or higher) characterized by good governance, inclusive growth and sustainable development.

Governments are increasingly looking for investors rather than donors. Conscious of the importance of a strong private sector to drive investment and innovation for socio-economic development, governments are devising schemes to support local businesses. As we have seen, the fund developed by Rwanda to foster a green economy provides competitive funds to successful public and private applicants. In Kenya, the Nairobi Industrial and Technology Park is being developed within a joint venture with a public institution, Jomo Kenyatta University of Agriculture and Technology.

In the past few years, governments have witnessed the economic spin-offs from the first technology incubators in Kenya, which have been incredibly successful in helping start-ups capture markets in information technology, in particular. Many governments are now investing in this dynamic sector, including those of Rwanda and Uganda. Spending on R&D is on the rise in most countries with innovation hubs, driven by greater investment by both the public and private sectors.

Most of the social innovation observed in East and Central Africa since 2009 tackles pressing development issues: overcoming food insecurity, mitigating climate change, the transition to renewable energy, reducing disaster risk and extending medical services. The leading technological breakthrough in the region (the MPesa payment service via a mobile phone) had been designed to bridge the rural–urban divide in access to banking services, addressing the financial needs of the poor masses at the bottom of the pyramid. This technology has since permeated virtually all sectors of the East African economy, mobile payments having become a common feature of banking services.

We have seen that both pan-African and regional bodies are themselves now convinced that STI is one of the keys to the continent's development. This is illustrated by the prizes for science and innovation offered by the African Union Commission and COMESA, for instance, and by the programme launched in 2014 by the African Development Bank to develop five centres of excellence in biomedical sciences.

The sources of East and Central Africa's heightened interest in STI are multiple but the global financial crisis of 2008–2009 certainly played a role. It boosted commodity prices and focused attention on beneficiation policies in Africa. The global crisis also provoked a reversal in brain drain, as visions of Europe and North America struggling with low growth rates and high unemployment discouraged emigration and encouraged some to return home. Returnees are today playing a key role in STI policy formulation, economic development and innovation. Even those who remain abroad are contributing: remittances are now overtaking FDI inflows to Africa.

The focus on sustainable development is a fairly new trend. The commodities boom in recent years has brought home to governments that they are sitting on a gold mine – literally, in some cases. Growing foreign interest in the natural endowments of countries such as Burundi, Cameroon, Gabon and Rwanda has made them increasingly conscious of the need to preserve their rare and valuable ecosystems to ensure their own sustainable development.

With 1 billion potential consumers across the continent, one key challenge will be to remove the barriers to intraregional and pan-African trade. An important step forward in this regard would be an overhaul of immigration laws within Africa. Currently, it is much easier for an average British or American citizen, for instance, to travel across Africa than for the average African. Reducing immigration requirements for Africans within Africa would considerably enhance the mobility of skilled personnel and knowledge spillovers.

By modernizing infrastructure, developing manufacturing and value addition, improving the business climate and removing barriers to pan-African trade, countries should be in a position to develop the local industries and jobs they will need to employ their rapidly growing populations. Greater regional integration will not only foster socio-economic development but also better governance and political stability, such as by favouring the multilateral resolution of disputes through dialogue, whenever possible, and through military means whenever unavoidable. The current co-operation between Cameroon, Chad, Niger and Nigeria to combat the Boko Haram terrorist sect illustrates this new paradigm of intra-regional co-operation. Another example is the EAC's decision to send a contingent of medical personnel to West Africa in October 2014 to help combat the Ebola epidemic.

KEY TARGETS FOR CENTRAL AND EAST AFRICA

- Raise GERD to 1% of GDP in countries of the region;
- Raise GERD in Kenya from 0.98% (2009) to 2% of GDP by 2014;
- Countries that signed the *Maputo Declaration* are to devote at least 10% of GDP to agriculture;
- Raise the proportion of Ethiopian women university students to 40%;
- Establish four technical secondary schools to raise the share of Gabonese pupils benefiting from this type of education from 8% to 20% by 2025;
- Raise the share of hydropower in Gabon's electricity matrix from 40% in 2010 to 80% by 2020;
- Establish a Green City of Education and Knowledge in Gabon by 2030, as well as a research fund and information technology park;
- Raise the amount of credit available to the private sector in Rwanda to 30% of GDP by 2018;
- Launch a pilot green city in Rwanda by 2018.

REFERENCES

AfDB (2012) *Interim Country Strategy Paper for Eritrea 2009–2011*. African Development Bank Group.

AfDB (2011) *Djibouti Country Strategy Paper 2011–2015*. African Development Bank Group. August.

AfDB (2010) Eastern Africa Regional Integration Strategy Paper 2011 – 2015. Revised Draft for Regional Team Meeting. African Development Bank. October.

AfDB,OECD and UNDP (2014) *African Economic Outlook 2014*. Regional Edition East Africa. African Development Bank, Organisation for Economic Co-operation and Development and United Nations Development Programme.

AMCOST (2013) Review of Africa's Science and Technology Consolidated Plan of Action (2005–2012). Final Draft. Study by panel of experts commissioned by African Ministerial Conference on Science and Technology.

AU–NEPAD (2010) *African Action Plan 2010–2015*: *Advancing Regional and Continental Integration in Africa.* African Union and New Partnership for Africa's Development.

BBC (2013) Kenya begins construction of 'silicon' city Konza. *BBC News*, 23 January.

Biztech Africa (2013) Uganda opens BPO incubation centre. *Biztech Africa*, 22 September.

UNESCO (2013) Education for *All Global Monitoring Report. Regional Fact Sheet, Education in Eastern Africa.* January. See: www.efareport.unesco.org.

Ezeanya, C. (2013) Contending Issues of Intellectual Property Rights, Protection and Indigenous Knowledge of Pharmacology in Africa of the Sahara. *The Journal of Pan African Studies,* 6 (5).

Flaherty, K., Kelemework, F. and K. Kelemu (2010) *Ethiopia: Recent Developments in Agricultural Research.* Ethiopian Institute of Agricultural Research. Country Note, November.

Hersman, E. (2012) From Kenya to Madagascar: the African tech-hub boom. *BBC News.* See: www.bbc.com/news/business-18878585

Irish, J. (2014) Chad to double oil output by 2016, develop minerals – minister. Reuters press release. *Daily Mai*l, 7 October.

IST-Africa (2012) *Guide to ICT Policy in IST-Africa Partner Countries.* Version 2.2, 20 April. Information Society Technologies Africa project.

Kulish, N. (2014) Rwanda reaches for new economic model. *New York Times*, 23 March.

Malouna, B. (2015) Développement durable : les inquiétudes de la société civile sur la nouvelle loi d'orientation. (Sustainable development : the concerns of civil society concerning the framework law). *Gabon Review*, 26 January. See www.gabonreview.com

MoFED (2013) *Growth and Transformation Plan. Annual Progress Report*. Ministry of Finance and Economic Development: Addis Ababa.

Muchie, M. and A. Baskaran (2012) *Challenges of African Transformation*. African Institute of South African Publishers.

Muchie, M.; Gammeltoft, P. and B. A. Lundvall (2003) *Putting Africa First: the Making of the African Innovation System*. Aalborg University Press: Copenhagen.

Nsehe, M. (2013) $1.6 million tech incubation program launched In Kenya. *Forbes Magazine*, 24 January.

Tumushabe, G.W. and J.O. Mugabe. (2012) *Governance of Science, Technology and Innovation in the East African Community*. The Inaugural Biennial Report 2012. Advocates Coalition for Development and Environment (ACODE) Policy Research Series No 51.

Urama, K. C. and E. Acheampong (2013) Social innovation creates prosperous societies. *Stanford Social Innovation Review*, 11 (2).

Urama, K., Ogbu, O.; Bijker, W.; Alfonsi, A.; Gomez, N. and N. Ozor (2010) *The African Manifesto for Science, Technology and Innovation*. Prepared by African Technology Policy Studies Network: Nairobi.

World Bank (2013) *Doing Business 2013. Smarter Regulations for Small and Medium-Size Enterprises*. World Bank Group.

WWAP (2014) *Water and Energy. World Water Development Report*. United Nations World Water Assessment Programme. UN–Water. Published by UNESCO: Paris.

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An important aspect of economic integration would be the transition from national innovation systems to a single regional innovation system.

Erika Kraemer-Mbula and **Mario Scerri**

A humanoid robot directs traffic at a busy intersection in Kinshasa, in the Democratic Republic of Congo. This solar-powered prototype is equipped with four cameras that allow it to record traffic. The information is then transmitted to a centre which analyses traffic infractions. This robot and its twin were designed by a group of Congolese engineers based at the Kinshasa Higher Institute of Applied Techniques (ISTA).
Photo: © Junior D. Kannah/AFP/Getty Images)

20 · Southern Africa

Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe

Erika Kraemer–Mbula and Mario Scerri

INTRODUCTION

Lifting trade barriers to foster regional integration

The Southern Africa Development Community (SADC) is home to 33% of sub-Saharan Africa's population and contributes about 43% of its GDP (US$ 684 billion in 2013). The region combines middle-income countries with some of the fastest-growing economies in Africa[1] and some of the poorest. Nothing underscores the region's diversity more than the fact that one country alone generates about 60% of GDP within the SADC and one-quarter of the continent's GDP: South Africa.

Despite this heterogeneity, there is considerable potential for regional integration, which is being increasingly driven by the Southern African Development Community (SADC). *A Protocol on Trade in Services* signed in 2012 seeks to negotiate progressively the removal of barriers to the free movement of services within the SADC.

Intra-SADC trade is relatively modest and has not grown to any significant degree in the past five years, owing partly to the similarity of the resource-based economies across the region, a cumbersome regulatory framework and inadequate border infrastructure (AfDB, 2013).[2] Nevertheless, compared to other African regional economic communities (see Box 18.2), the SADC bloc still displays the most dynamic intraregional trade of the continent, albeit mostly directed towards South Africa. The SADC trades very little with the rest of Africa, the region's trade being mostly oriented towards the rest of the world.

On 10 June 2015, the 26 countries which make up the three regional communities of SADC, the Common Market for Southern and Eastern Africa (COMESA) and the East African Community (EAC) formally launched a Free Trade Area. This should accelerate regional integration.[3]

Relative political stability

The SADC region enjoys relative political stability and democratic political processes, although internal fragmentation continues to characterize the ruling political parties in most countries. For the past six years, SADC membership has remained relatively stable, with the exception of Madagascar, which was suspended in 2009 following a coup d'état then reintegrated in January 2014 after its return to constitutional government. If Madagascar is now emerging from five years of political turmoil and international sanctions, the Democratic Republic of Congo is still recovering from the violence inflicted by armed groups who were neutralized by a United Nations peacekeeping force in 2013. Political tensions remain in Lesotho, Swaziland and Zimbabwe.

The SADC is striving to maintain peace and security within its member states, including through the SADC tribunal, which was established in Gaborone (Botswana) in 2005 then dismantled in 2010 before being revived by a new protocol in 2014, albeit with a diminished mandate. The SADC Regional Early Warning Centre is also based in Gaborone. This centre was established in 2010 to prevent, manage and resolve conflict, in conjunction with national early warning centres.

In 2014, five SADC countries held presidential elections – Botswana, Malawi, Mozambique, Namibia and South Africa – Namibia being the first African country to cast presidential ballots electronically through an e-voting system. The SADC aims to attain equal representation of men and women in key decision-making positions by 2015, through the *SADC Protocol on Gender and Development*, which entered into force in early 2013 after being signed in 2008. However, only five SADC countries are anywhere near reaching parity in parliament, having gone above the 30% threshold set previously by regional leaders for the representation of women: Angola, Mozambique, Seychelles, South Africa and Tanzania. Of note is that President Joyce Banda of Malawi became the SADC's first woman president in 2012. Three years later, renowned biologist Ameenah Gurib-Fakim made history by becoming Mauritius' first woman president.

Widespread poverty in two-thirds of countries

The population is growing fast, at 2.5% per year on average between 2009 and 2013. By 2013, the region counted a combined population of over 294 million. Human development varies widely, from a high of 0.771 on the UNDP's index in Mauritius to a low of 0.337 in the Democratic Republic of Congo. A promising trend is that ten countries advanced in the overall world ranking from 2008 to 2013. Madagascar, Seychelles and Swaziland, on the other hand, have slipped a few places (Table 20.1).

The SADC's aggregate economy still displays features of a developing region, with worrying unemployment levels in some countries. Poverty and inequality persist, despite

1. The Democratic Republic of Congo, Mozambique, Tanzania, Zambia and Zimbabwe experienced annual average GDP growth of about 7% from 2009 to 2013 but these five countries, along with Angola, Lesotho and Malawi, are also currently listed by the United Nations as being least developed countries.

2. In 2008, intra-SADC imports constituted only 9.8% of the region's total imports and intra-SADC exports 9.9% of SADC's total exports. Being the most diversified economy, South Africa is also the dominant exporter (68.1% of all intra-SADC exports) but only accounted for 14.8% of intra-SADC imports in 2009.

3. For the composition of these regions, see Annex I.

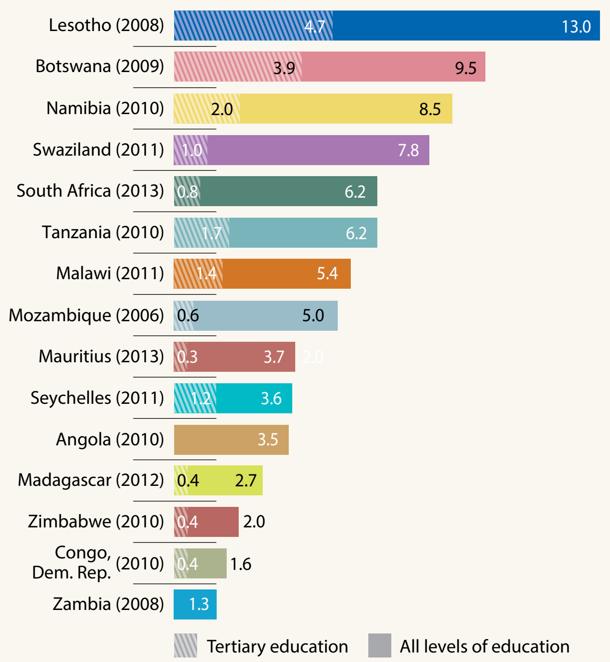
Table 20.1: **Social landscape of Southern Africa**

	Population (millions), 2013	Change since 2009 (%)	HDI ranking, 2013 (change since 2008)	Unemployment rate, 2013 (% of total labour force)	Poverty rate*, 2010 (change since 2000)	Gini, 2010 (change since 2000)
Angola	21.5	13	$149^{(2)}$	6.8	$67.42^{(-)}$	$42.60^{(-)}$
Botswana	2.0	4	$108^{(2)}$	18.4	$27.83^{(-)}$	$60.46^{(-)}$
Congo, Dem. Rep.	67.5	12	$187^{(1)}$	8.0	95.15	44.43
Lesotho	2.1	4	$163^{(0)}$	24.7	$73.39^{(-)}$	$54.17^{(+)}$
Madagascar	22.9	12	$155^{(-3)}$	3.6	$95.1^{(+3)}$	$40.63^{(+)}$
Malawi	16.4	12	$174^{(0)}$	7.6	$88.14^{(-)}$	$46.18^{(+)}$
Mauritius	1.2	1	$63^{(9)}$	8.3	$1.85^{(+)}$	$35.90^{(+)}$
Mozambique	25.8	11	$179^{(1)}$	8.3	$82.49^{(-)}$	$45.66^{(-)}$
Namibia	2.3	7	$127^{(3)}$	16.9	$43.15^{(-)}$	$61.32^{(-)}$
Seychelles	0.1	2	$70^{(-12)}$	–	1.84	65.77
South Africa	52.8	4	$119^{(2)}$	24.9	$26.19^{(-)}$	$65.02^{(-)}$
Swaziland	1.2	6	$148^{(-5)}$	22.5	$59.11^{(-)}$	$51.49^{(-)}$
Tanzania	49.3	13	$160^{(5)}$	3.5	$73.00^{(-)}$	$37.82^{(+)}$
Zambia	14.5	13	$143^{(7)}$	13.3	$86.56^{(+)}$	$57.49^{(+)}$
Zimbabwe	14.1	10	$160^{(16)}$	5.4	–	–
TOTAL SADC	293.8	10	–	–	–	–

* calculated as the share of the population living on less than US $2 per day.
Note: The reference year for the poverty rate and Gini index is 2010 or the closest year; see glossary, p.738.

Source: World Bank's World Development indicators, April 2015; for HDI: UNDP's *Human Development Reports*

Figure 20.1: **Public expenditure on education in Southern Africa as a share of GDP, 2012 or closest year (%)**



Source: UNESCO Institute for Statistics, May 2015

the fact that health and education remain top priorities for most countries, accumulating substantial portions of public expenditure (see Figure 20.1 and Table 19.2). The proportion of the population living on less than US$ 2 a day remains extremely high in ten SADC countries for which data are available (Table 20.1). Moreover, even the Seychelles and South Africa, where a fraction of the population lives beneath the poverty line, report high levels of inequality, which even increased over the period 2000–2010.

Foreign investment has doubled since 2007

Foreign direct investment (FDI) in Southern Africa almost doubled from 2007 to 2013 to US$ 13 billion. This was mainly due to record high inflows to South Africa and Mozambique, mostly for infrastructure development and the gas sector in Mozambique (Table 20.2). The proportion of national investment financed by donors is a good proxy indicator of the degree of economic self-sustainability. Once again, the region shows a high level of disparity in the degree of self-sustainability, with a clear distinction between countries that exhibit virtually no reliance on overseas development assistance (ODA) for national investment requirements and those where ODA is a significant contributor. Lesotho, Malawi and Swaziland show a growing reliance on ODA over the period under study. In other countries, such as Mozambique, Tanzania, Zambia and

Table 20.2: **Economic landscape of Southern Africa**

	GDP per capita in PPP$ millions (2011 constant prices)			GDP growth		Overseas development assistance/GFCF*			Patents, 2008–2013
	2009	2013	5-year change (%)	2009 (%)	2013 (%)	2009 (%)	2013 (%)	FDI inflow, 2013 (% of GDP)	
Angola	7 039	7 488	6.4	2.4	6.8	2.1	1.6	-5.7	7
Botswana	12 404	15 247	22.9	-7.8	5.8	7.8	2.2	1.3	0
Congo, Dem. Rep.	657	783	19.1	2.9	8.5	87.2	38.3	5.2	0
Lesotho	2 101	2 494	18.7	3.4	5.5	26.5	33.0^{-1}	1.9	0
Madagascar	1 426	1 369	-4.0	-4.0	2.4	14.9	30.0	7.9	0
Malawi	713	755	5.9	9.0	5.0	64.3	153.9	3.2	0
Mauritius	15 018	17 146	14.2	3.0	3.2	6.7	5.9	2.2	0
Mozambique	893	1 070	19.7	6.5	7.4	130.8	85.0	42.8	0
Namibia	8 089	9 276	14.7	0.3	5.1	13.1	7.8	6.9	2
Seychelles	19 646	23 799	21.1	-1.1	5.3	9.8	5.2	12.3	2
South Africa	11 903	12 454	4.6	-1.5	2.2	1.7	1.8	2.2	663
Swaziland	6 498	6 471	-0.4	1.3	2.8	17.2	31.9	0.6	6
Tanzania	2 061	2 365	14.7	5.4	7.3	35.6	26.2	4.3	4
Zambia	3 224	3 800	17.8	9.2	6.7	–	17.4^{-3}	6.8	0
Zimbabwe	1 352	1 773	31.2	6.0	4.5	76.7	46.3	3.0	4

-*n* = data refer to *n* years before reference year
*Gross fixed capital formation, see the glossary, p. 738

Source: World Bank's World Development Indicators, April 2015; patent data from USPTO database

Zimbabwe, this reliance has dropped significantly in recent years, even if it remains high.

The SADC economy is highly dependent on natural resources, with mining and agriculture constituting substantial segments of economic activity. From Figure 20.2, we can see that the production structure of most SADC economies tends to be resource-based, with a relatively small manufacturing sector, except in Swaziland. The region is vulnerable to extreme weather events such as cyclical drought and flooding. Angola, Malawi and Namibia have all experienced below-normal rainfall in recent years, affecting food[4] security. In 2014, Madagascar embarked on a nation-wide campaign to contain a locust outbreak which threatened staple crops. There has been a worrying drop in government funding for agricultural R&D by SADC countries and development agents, despite the continent's commitment, in the *Maputo Declaration* (2003), to devoting at least 10% of GDP to agriculture. By 2010, only a handful of SADC countries devoted more than 5% of GDP to agriculture, notably Madagascar, Malawi, Tanzania and Zambia (see Table 19.2).

The region's strong dependence on natural resources has led to wild economic fluctuations and rendered it vulnerable to global economic crises, such as that which led to an economic slowdown in 2009. Since 2010, the region has enjoyed persistent growth, with prospects for a return to pre-2009 growth rates of 5–6% in 2015 (AfDB *et al*., 2014).

Four ratifications of SADC protocol on STI

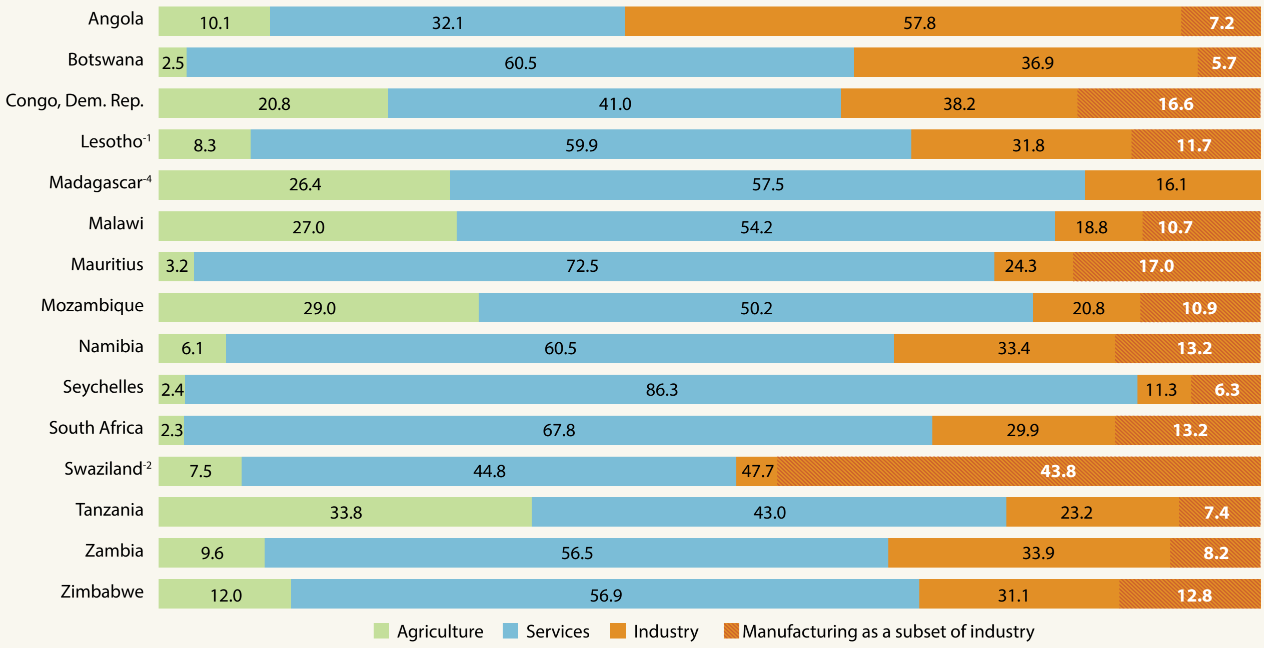
The Southern African Development Community Treaty of 1992 provides the legal framework for co-operation among SADC member states. It has since been enriched by the adoption of 27 protocols in priority areas.[5] In its *Protocol on Science, Technology and Innovation* (2008), the SADC stresses the importance of S&T for achieving 'sustainable and equitable socio-economic growth and poverty eradication'. It provides the basis for the development of institutional mechanisms for regional co-operation and co-ordination in the following areas:

- policy training;
- the role of women in science;
- strategic planning;

4. The Regional Early Warning System, Famine Early Warning System and Climate Services Centre are all based at the SADC centre in Gaborone (Botswana). The SADC Plant Genetic Resource Centre is located in Lusaka (Zambia). All were established about two decades ago. See www.sadc.int

5. The SADC Treaty calls for the harmonization of political and socio-economic policies for the region to attain the objective of sustainable development, whereas the protocols promote legal and political co-operation.

Figure 20.2: **GDP in SADC countries by economic sector, 2013 or closest year**



-*n* = data refer to *n* years before reference year

Source: World Bank's World Development Indicators, April 2015

- intellectual property rights;
- indigenous knowledge systems;
- climate change; and
- high-performance computing, as exemplified by the Blue Gene project launched by IBM in 1999, which spent the next decade developing supercomputers with low power consumption.

The protocol is based on a broad definition that extends considerably beyond science and technology.[6] A portfolio committee briefing by the South African Department of Science and Technology (RSA, 2011) notes that the protocol is an essential first step towards regional integration, with steady growth in self-financed bilateral co-operation. It considers that the SADC has become Africa's leading regional economic community. However, the briefing also points out that the regional STI desk remains under-resourced and mostly ineffectual. As a result, member states are still reluctant to support it. To date, the protocol has only been ratified by four countries: Botswana, Mauritius, Mozambique and South Africa. For the protocol to enter into force, it must be ratified by two-thirds of member states (10 countries).

6. The term 'national innovation system' refers to 'a set of functioning institutions, organisations and policies which intervene constructively in pursuit of a common set of social and economic objectives', as defined by the SADC Secretariat in 2008.

Two primary policy documents operationalize the SADC Treaty, *the Regional Indicative Strategic Development Plan* for 2005–2020 (RISDP, 2003) and the *Strategic Indicative Plan for the Organ* (SIPO, 2004). The RISDP identifies the region's 12 priority areas for both sectorial and cross-cutting intervention, mapping out goals and setting up concrete targets for each. The four sectorial areas are: trade and economic liberalization, infrastructure, sustainable food security and human and social development. The eight cross-cutting areas are:

- poverty;
- combating the HIV/AIDS pandemic;
- gender equality;
- science and technology;
- information and communication technologies (ICTs);
- environment and sustainable development;
- private sector development; and
- statistics.

Targets include:

- ensuring that 50% of decision-making positions in the public sector are held by women by 2015;
- raising gross domestic expenditure on research and development (GERD) to at least 1% of GDP by 2015;

- increasing intra-regional trade to at least 35% of total SADC trade by 2008 (10% in 2008);
- increasing the share of manufacturing to 25% of GDP by 2015 (Figure 20.2); and
- achieving100% connectivity to the regional power grid for all member states by 2012 (see Table 19.1).

A 2013 mid-term review of RISDP noted that limited progress had been made towards STI targets, owing to the lack of human and financial resources at the SADC Secretariat to co-ordinate STI programmes. In Maputo in June 2014, SADC ministers of STI, education and training adopted the SADC *Regional Strategic Plan on Science, Technology and Innovation for 2015–2020* to guide implementation of regional programmes.

A vulnerable environment despite legal frameworks

The region's commitment to sustainable development is reflected in the SADC Treaty and countries' active participation in major multilateral environmental[7] agreements. Although there has been some progress in environmental management in recent years, Southern Africa remains very vulnerable to climate change; it also suffers from high levels of pollution, biodiversity loss, inadequate access to clean water and sanitation services (see Table 19.1), land degradation and deforestation. It has been estimated that over 75% of land is partially degraded and 14% severely degraded. Soil erosion has been identified as the primary cause of declining agricultural production. For the past 16 years, the SADC has had a protocol governing wildlife, forestry, shared water courses and the environment, including climate change, the *SADC Protocol on Wildlife Conservation and Law Enforcement* (1999).

More recently, SADC has initiated a number of regional and national initiatives to mitigate the impact of climate change. In 2013, ministers responsible for the environment and natural resources approved the development of the SADC Regional Climate Change programme. In addition, COMESA, EAC and SADC have been implementing a joint five-year initiative since 2010 known as the Tripartite Programme on Climate Change Adaptation and Mitigation, or The African Solution to Address Climate Change. Five SADC countries have also signed the *Gaborone Declaration for Sustainability in Africa* (Box 20.1).

Regional policy frameworks, a continental strategy

In 2014, the *Science, Technology and Innovation Strategy for Africa* (STISA–2024) replaced Africa's previous decadal framework, *Africa's Science and Technology Consolidated Plan of Action* (CPA, 2005–2014). The CPA had been the continent's first consolidated attempt to accelerate Africa's transition to an innovation-led knowledge economy. As part of the *Plan of Action,* several networks of centres of excellence have been set up. Within the African Biosciences Initiative, four subregional hubs have been established, including the Southern African Network for Biosciences (SANbio), based at the Council for Scientific and Industrial Research in Pretoria since 2005 (see Box 19.1). SADC countries also participate in the African Biosafety Network of Expertise (see Box 19.1).

However, the CPA implementation raised a number of concerns related to:

- its narrow focus on generating R&D, with less concern for the use of scientific output;
- insufficient funding to allow full implementation of programmes;
- excessive reliance on external financial support targeting short-term activities and solutions; and
- the failure to link it with other pan-African policies such as continent-wide agriculture and environmental protection projects.

STISA emerged in 2014, following a high-level review of the CPA (see p. 505). This strategic framework is the next decadal stepping stone towards the goals of the African Union's *Agenda 2063*, also known as 'the Africa we want.' In *Agenda 2063,* the African Union provides a broad vision and action plan for building a more prosperous and united Africa over the next 50 years. STISA displays a stronger focus on innovation and science for development than its predecessor. It foresees the establishment of an African Science, Technology and Innovation Fund (ASTIF) but the financial sources needed to operate the fund remain undetermined. The lack of committed funds from member states and the broadness of STISA's objectives have raised multiple questions as to the feasibility of its implementation. It will take more than a commitment from member states to devoting 1% of GDP to R&D – the target enshrined in the African Union's *Khartoum Declaration* of 2007 – to make ASTIF operational.

In adopting STISA in 2014, the heads of state and government called upon member states, regional economic communities and development partners to align, connect and use STISA as a reference framework in designing and co-ordinating their own development agendas for STI.

Concerning intellectual property, the proposal to create a Pan-African Intellectual Property Organization (PAIPO) has regained momentum since the idea was first put forward in 2007 at the African Union Summit in Khartoum. However, the development and publication in 2012 of the draft statutes creating PAIPO have been the object of substantial criticism, from questioning the impact of stronger intellectual property protection in Africa to concerns about how PAIPO would

7. such as the UN Framework Convention on Climate Change, UN Convention to Combat Desertification, the UN Convention on Biological Diversity and the Ramsar Convention on Wetlands

Box 20.1 **The Gaborone Declaration for Sustainability in Africa**

In May 2012, the heads of state of Botswana, Gabon, Ghana, Kenya, Liberia, Mozambique, Namibia, Rwanda, South Africa and Tanzania gathered in Gaborone for a two-day summit, in the company of several public and private partners.

By adopting the *Gaborone Declaration for Sustainability in Africa*, the ten countries engaged themselves in a multi-year process. They recommitted to implementing all conventions and declarations promoting sustainable development and undertook to:

- integrate the value of natural capital into national accounting and corporate planning and reporting processes, policies and programmes;
- build social capital and reduce poverty by transitioning agriculture, extractive industries, fisheries and other natural capital uses to practices that promote sustainable employment, food security, sustainable energy and the protection of natural capital through protected areas and other mechanisms;
- build knowledge, data, capacity and policy networks to promote leadership and a new model of sustainable development and to increase momentum for positive change.

The overall objective of the *Declaration* was 'to ensure that the contributions of natural capital to sustainable economic growth, maintenance and improvement of social capital and human well-being are quantified and integrated into development and business practice.' This statement was propelled by the signatories' realization that GDP has its limitations as a measure of well-being and sustainable growth.

The interim secretariat of this initiative is being hosted by the Department of Environmental Affairs within the Botswanan Ministry of Environment Wildlife and Tourism, with technical support from Conservation International, a non-governmental organization. Conservation International has pledged funding for a situational analysis which will provide baseline information on where the ten countries stand with respect to the agreed actions outlined above and set priorities for moving forward.

Since the 2012 summit, an implementation framework has been drafted to track progress. In 2012, for instance, Gabon adopted a strategic plan to 2025 which foresees integrating natural capital into the national accounting system and the adoption of a national climate plan, among other moves to foster sustainable development (see p. 521).

Source: www.gaboronedeclaration.com

align its mandate with those of the two existing regional organizations, the African Regional Intellectual Property Organisation (ARIPO)[8] and the African Intellectual Property Organisation for French-speaking Africa, which already operate under separate regimes themselves.

The *Swakopmund Protocol on the Protection of Traditional Knowledge and Expressions of Folklore* was adopted in Namibia in April 2010 by nine ARIPO member States: Botswana, Ghana, Kenya, Lesotho, Liberia, Mozambique, Namibia, Zambia and Zimbabwe. The protocol will only enter into force once six ARIPO member states have deposited instruments of ratification (for signatories) or accession (for non-signatories), which was not the case in 2014. Any state that is a member of the African Union or the United Nations Economic Commission for Africa (UNECA) may also sign up to it.

The *AU–NEPAD African Action Plan for 2010–2015* expressly underscores the important role that harmonized regional policies could play in adapting to climate change. Africa's commitment to protecting its unique natural resources is guided at pan-African level by the African Model Law for the Protection of the Rights of Local Communities, Farmers and Breeders and for the Regulation of Access to Biological Resources (2001). The prioritization of biodiversity conservation in pan-African programmes and policies was again manifest in 2011 when the African Union encouraged all member states to adhere to international agreements on biodiversity, including the *Nagoya Protocol on Access to Genetic Resources and Sharing of Benefits Arising from their Utilization* and the *Convention on Biological Diversity* (2010).

TRENDS IN STI GOVERNANCE

Two-thirds of SADC countries have STI policies

Despite the different stages of development in terms of STI governance in Southern Africa, there is a shared and common interest in achieving sustainable development through the promotion of STI. This has engendered a plethora of institutional arrangements and bodies mandated with co-ordinating and supporting STI, as well as widespread formulation of related policies and strategies. Innovation, however, remains a secondary objective of policy formulation and, although policies are intended to support the STI ecosystem,

8. The current members of ARIPO are Botswana, Gambia, Ghana, Kenya, Lesotho, Malawi, Mozambique, Namibia, Sierra Leone, Liberia, Rwanda, São Tomé & Príncipe, Somalia, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe.

they remain firmly linked to the state apparatus for S&T, with little participation by the private sector in policy design. In 2014, 11 out of the 15 SADC countries had STI policies in place (Table 20.3). However, STI policy documents are rarely accompanied by implementation plans and allocated budgets for implementation. Some SADC countries without dedicated policies for STI nevertheless appear to be relatively active in developing programmes to promote university–industry collaboration and innovation. Mauritius is one such example (see p. 551).

A study conducted by UNESCO within its Global Observatory of STI Policy Instruments (GO→SPIN) found a high correlation between scientific productivity and effective governance. Only seven African countries shared positive values for both government effectiveness and political stability: Botswana, Cabo Verde, Ghana, Mauritius, Namibia, the Seychelles and South Africa. The great majority of African countries had negative values for both indicators, including Angola, the Democratic Republic of Congo, Swaziland and Zimbabwe (UNESCO, 2013).

Disparities in research and development (R&D) are evident across the region. This phenomenon is illustrated by the GERD/GDP ratio, which ranges from a low of 0.01% in Lesotho to a high of 1.06% in Malawi (Figure 20.3). South Africa's own ratio (0.73%) is down from 0.89% in 2008. South Africa filed 96% of SADC patents between 2008 and 2013 and, together with Botswana, counts by far the greatest density of researchers (Figure 20.4). South Africa also stands out for the fairly equal division between the government (45%) and business enterprise (38%) sectors in terms of R&D funding and thus the maturity of industrial R&D in this country (see Table 19.5).

SADC economies have receded in the KEI

Only four SADC countries have conducted national innovation surveys under the African Science, Technology and Innovation Indicators (ASTII) programme, making comparisons subject to caution. What does emerge from the ASTII report published in 2014 is that the percentage of firms describing themselves as being innovation active is quite high, with 58.5% in Lesotho, 65.4% in South Africa, 61.3% in Tanzania and 51% in Zambia.

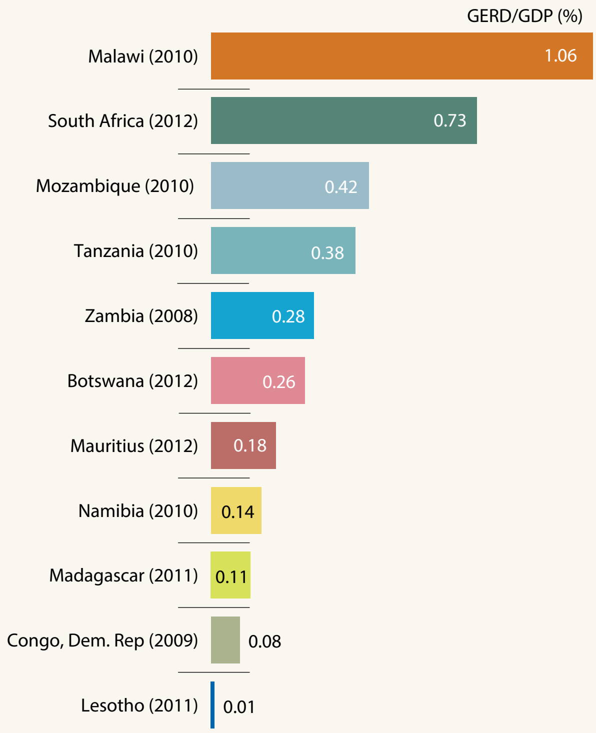
Table 20.4 presents SADC rankings in the World Bank's Knowledge Economy Index (KEI) and Knowledge Index (KI). Although these indices are largely based on the perceptions of the business sector and offer an inevitably biased view of the national innovation system, they do offer a basis for comparison. It is evident from this table that most SADC economies have receded in these international rankings since 2000, with Botswana, South Africa and Lesotho sliding the most. The four countries showing the highest KEI values are Mauritius, South Africa, Botswana and Namibia. South Africa is seen as having the most developed innovation system, whereas Mauritius offers the strongest incentive regime.

Table 20.3: **STI planning in SADC countries**

	STI policy document	Date of adoption/ period of validity
Angola	Yes	2011
Botswana	Yes	1998; 2011
Congo, Dem. Rep.	No	
Lesotho	Yes	2006–2011
Madagascar	Yes	2013
Malawi	Yes	2011–2015
Mauritius	No	
Mozambique	Yes	2003; 2006–2016
Namibia	Yes	1999
Seychelles	No	
South Africa	Yes	2010
Swaziland	(draft)	
Tanzania	Yes	1996; 2010
Zambia	Yes	1996
Zimbabwe	Yes	2002; 2012

Source: compiled by authors

Figure 20.3: **GERD/GDP ratio in Southern Africa, 2012 or closest year**



Source: UNESCO Institute for Statistics, August 2015; for Malawi: UNESCO (2014a)

Gender equity to be enshrined in national constitutions

Gender inequality is still a major social issue in Southern Africa. Women make up more than four out of ten researchers in just three countries: Mauritius, Namibia and South Africa (Figure 20.5). Only three countries report female participation in research across the public and private sectors: Botswana, South Africa and Zambia.

The *SADC Protocol on Gender and Development* (2008)[9] set ambitious targets in this respect. One target stipulates that States Parties are to endeavour to ensure that 'by 2015, at least 50% of decision-making positions in the public and private sectors are held by women, including [through] the use of affirmative action.' Currently, South Africa (42%), Angola (37%), Mozambique (35%) and Namibia (31%) have achieved a participation rate of 30% and above for women in political representation but other countries lag far behind, including Botswana (11%). In Malawi, the proportion of parliamentary seats held by women increased from 14% to 22% between 2004 and 2009.

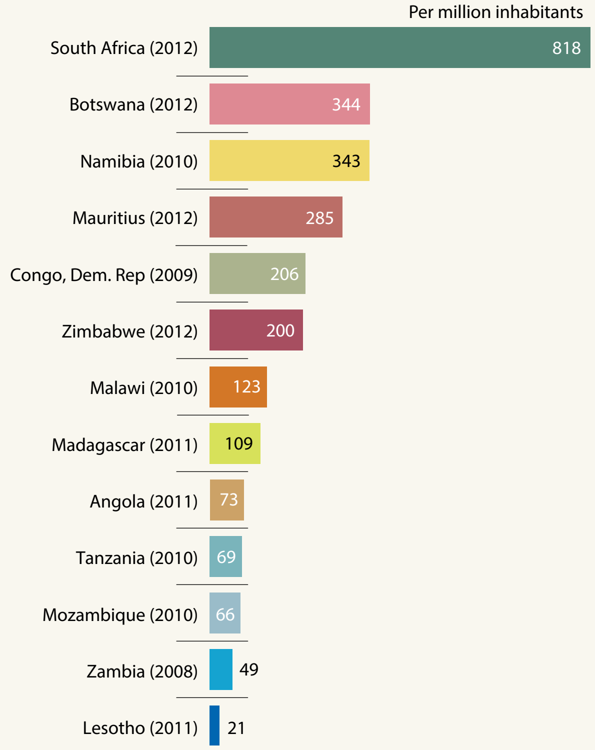
The protocol recommends that gender equity be enshrined in national constitutions by 2015. State Parties are also to enact laws by this date which promote equal access to, and retention at, all levels of education, including tertiary. By 2014, only seven countries had achieved parity in primary education,[10] nine countries[11] had passed the threshold of a minimum of 50% female enrolment in secondary schools and seven counted more young women at university than young men[12] in 2014 (Morna *et al.*, 2014). It is clear that most Southern African countries will not achieve either the targets of the *SADC Protocol on Gender and Development* or the Millennium Development Goal on gender equality by 2015.

SADC students among world's most mobile

'SADC students are among the most mobile in the world, with six out of every 100 tertiary students studying abroad' (UIS, 2012). In 2009, 89 000 SADC students studied outside their home country, representing 5.8% of tertiary enrolment in the region. This ratio is higher than the regional average for sub-Saharan Africa (4.9%) and three times the world average (2.0%).

One explanation can be found in the SADC *Protocol on Education and Training* (1997), which sets out to facilitate mobility. Only three signatory countries (South Africa, Swaziland and Zimbabwe), however, have respected the agreement in the protocol that countries cease charging higher fees for SADC students than for national students, a practice considered a potential barrier to student mobility (UIS, 2012).

Figure 20.4: **Researchers (HC) in Southern Africa per million inhabitants, 2013 or closest year**



Source: UNESCO Institute for Statistics, April 2015

Students who travel abroad from Botswana, Lesotho, Madagascar, Namibia, Swaziland and Zimbabwe tend to be concentrated in a single destination: South Africa.[13] The latter hosted about 61 000 international students in 2009, two-thirds of whom came from other SADC nations. South Africa is not only the leading host country in Africa but also ranks 11th among host countries worldwide. Its higher education sector is well developed, with strong infrastructure and several respected research institutions that appeal to international students. Students from Angola, Malawi, Mozambique, the Seychelles, South Africa, Tanzania and Zambia tend to be dispersed across a wide range of host countries (UIS, 2012).

A growing number of publications

South Africa stands out for having the greatest number of researchers per million inhabitants (Figure 20.4) and by far the greatest output in terms of publications and patents (Figure 20.6 and Table 20.2). When population is taken into account, it comes second only to Seychelles for the number of articles.

9. This protocol was signed by all but three SADC countries: Botswana, Malawi and Mauritius.

10. Botswana, Malawi, Seychelles, South Africa, Swaziland, Tanzania and Zimbabwe

11. Botswana, Lesotho, Madagascar, Mauritius, Namibia, Seychelles, South Africa, Swaziland and Zimbabwe

12. Botswana, Lesotho, Mauritius, Namibia, South Africa, Swaziland and Zambia

13. with the exception of students from Madagascar, who prefer France

Table 20.4: **KEI and KI rankings for 13 SADC countries, 2012**

Rank	Change in rank since 2000	Country	Knowledge Economy Index	Knowledge Index	Economic Incentive Regime	Innovation	Education	ICTs
62	1	**Mauritius**	5.5	4.6	8.22	4.41	4.33	5.1
67	-15	**South Africa**	5.2	5.1	5.49	6.89	4.87	3.6
85	-18	**Botswana**	4.3	3.8	5.82	4.26	3.92	3.2
89	-9	**Namibia**	4.1	3.4	6.26	3.72	2.71	3.7
106	-9	**Swaziland**	3.1	3.0	3.55	4.36	2.27	2.3
115	-4	**Zambia**	2.6	2.0	4.15	2.09	2.08	1.9
119	-6	**Zimbabwe**	2.2	2.9	0.12	3.99	1.99	2.6
120	-12	**Lesotho**	2.0	1.7	2.72	1.82	1.71	1.5
122	-6	**Malawi**	1.9	1.5	3.33	2.65	0.54	1.2
127	-2	**Tanzania**	1.8	1.4	3.07	1.98	0.83	1.3
128	-2	**Madagascar**	1.8	1.4	2.79	2.37	0.84	1.1
129	5	**Mozambique**	1.8	1.0	4.05	1.76	0.17	1.1
142	-1	**Angola**	1.1	1.0	1.48	1.17	0.32	1.4

Note: Rankings are for a total of 145 countries.

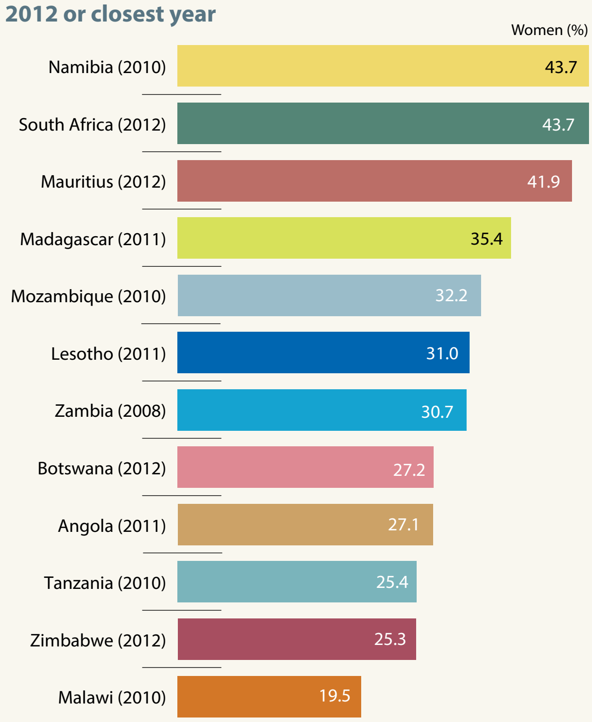
Source: World Bank

South Africa increased the number of its publications by 23% from 2009 to 2014 but the strongest growth rate was recorded by Angola and the Democratic Republic of Congo, albeit from a low base. The most prolific countries can boast of an average citation rate above the G20 average (Figure 20.6).

With nearly one-third of their publications concentrated in chemistry, engineering, mathematics and physics over the 2008–2014 period, Mauritius and South Africa are more akin to developed countries than other SADC countries where research tends to favour health-related sciences. Almost all countries share an inclination for geosciences, however (Figure 20.6).

When it comes to international collaboration, South African and Mauritian scientists stand out once more. Whereas just over half of South African articles (57%) and two-thirds of Mauritian articles (69%) had a foreign author over 2008–2014, the ratio among their SADC neighbours varied from 80% in Botswana to 96% in Mozambique and Zambia.

Figure 20.5: **Women researchers (HC) in Southern Africa, 2012 or closest year**



Note: Data are unavailable for some countries.

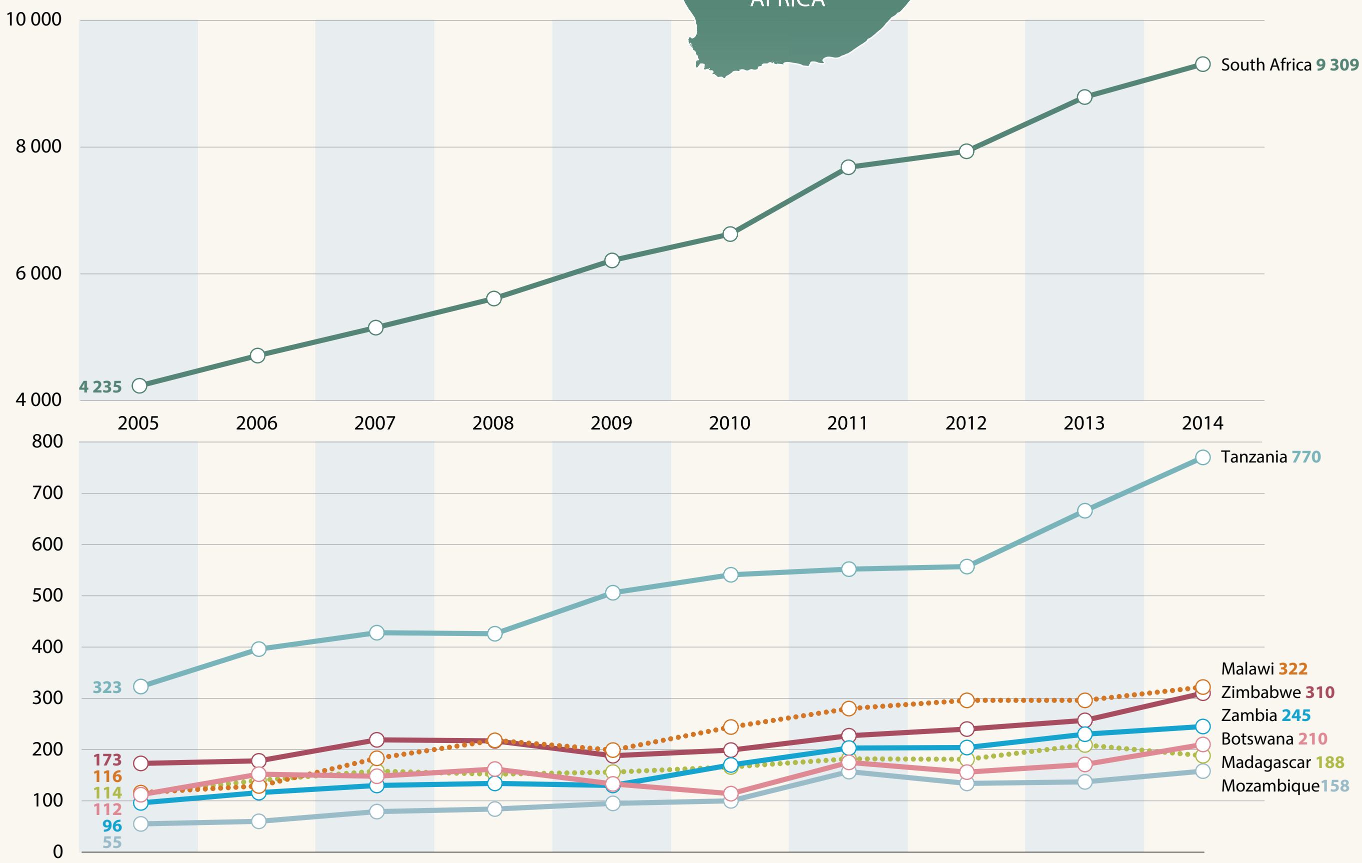
Source: UNESCO Institute for Statistics, April 2015

Figure 20.6: **Scientific publication trends in SADC countries, 2005–2014**

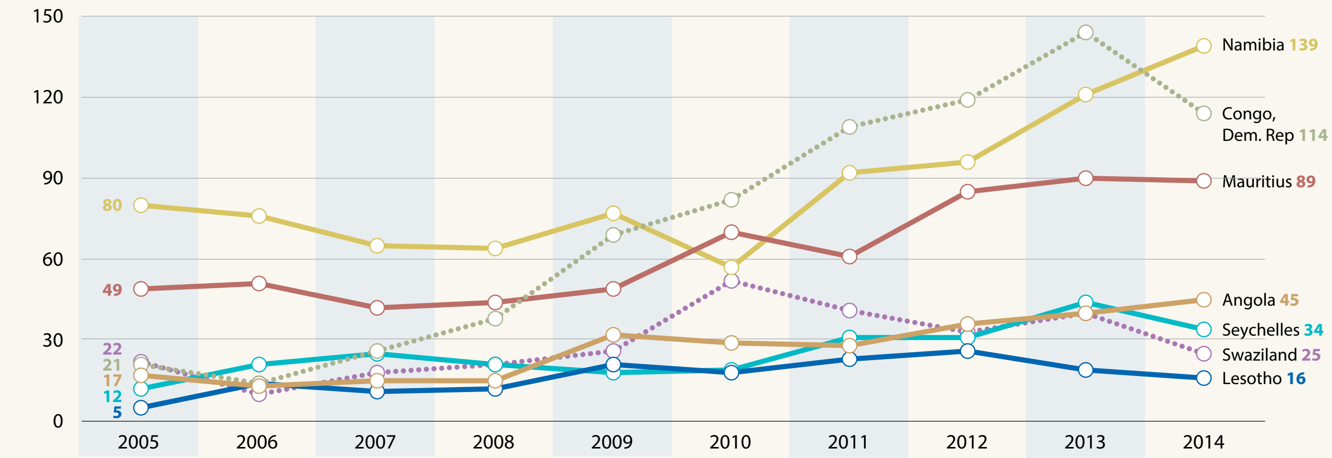
1.20

Average citation rate, 2008–2012, for the four countries with the most output: South Africa, Tanzania, Malawi and Zimbabwe; the G20 average is 1.02

Output from Malawi and Mozambique has almost tripled since 2005

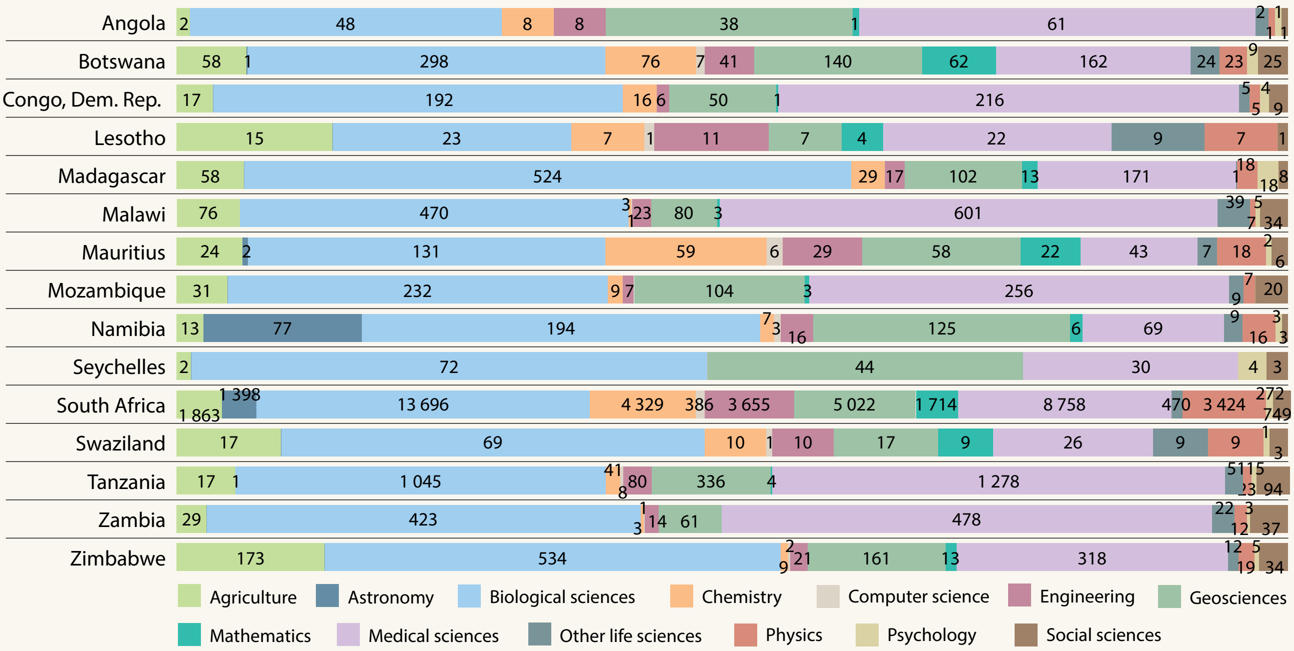


Strong growth in Angola and the Democratic Republic of Congo



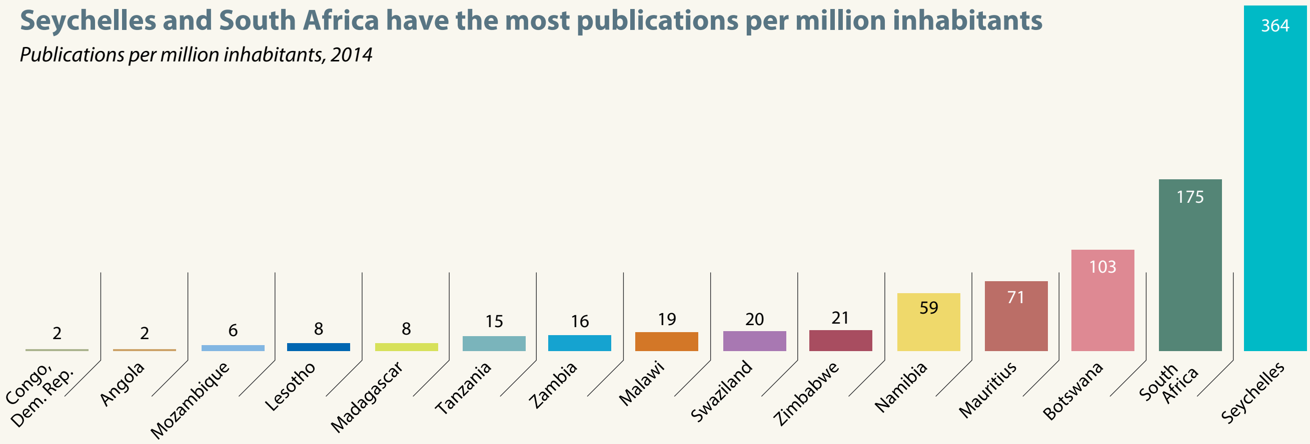
Life sciences and geosciences dominate

Cumulative totals by field, 2008–2014



Seychelles and South Africa have the most publications per million inhabitants

Publications per million inhabitants, 2014



South Africa is a key research partner for most SADC countries

Main foreign partners, 2008–2014 (number of papers)

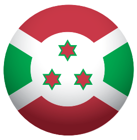
	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Angola	Portugal (73)	USA (34)	Brazil (32)	UK (31)	Spain/France (26)
Botswana	USA (367)	South Africa (241)	UK(139)	Canada (58)	Germany (51)
Congo, Dem. Rep.	Belgium (286)	USA (189)	France (125)	UK (77)	Switzerland (65)
Lesotho	South Africa (56)	USA (34)	UK (13)	Switzerland (10)	Australia (8)
Madagascar	France (530)	USA (401)	UK (180)	Germany (143)	South Africa (78)
Malawi	USA (739)	UK (731)	South Africa (314)	Kenya /N.lands (129)	
Mauritius	UK (101)	USA (80)	France (44)	India (43)	South Africa (40)
Mozambique	USA (239)	Spain (193)	South Africa (155)	UK (138)	Portugal (113)
Namibia	South Africa (304)	USA (184)	Germany (177)	UK (161)	Australia (115)
Seychelles	UK (69)	USA (64)	Switzerland (52)	France (41)	Australia (31)
South Africa	USA (9 920)	UK (7 160)	Germany (4 089)	Australia (3 448)	France (3 445)
Swaziland	South Africa (104)	USA (59)	UK (45)	Switz./ Tanzania (12)	
Tanzania	USA (1 212)	UK (1 129)	Kenya (398)	Switzerland (359)	South Africa (350)
Zambia	USA (673)	UK (326)	South Africa (243)	Switzerland (101)	Kenya (100)
Zimbabwe	South Africa (526)	USA (395)	UK (371)	Netherlands (132)	Uganda (124)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

The following section will be analysing the viability of national innovation systems, in terms of their potential to survive, grow and evolve. We shall be employing a broad 'national innovation systems' approach to examining the interconnectedness of STI and development (Table 20.5).

ANGOLA



Progress in higher education, despite governance issues

Angola is considered as having a viable national innovation system (Table 20.5). The biggest obstacle to the country's development prospects lies in governance. Angola ranks poorly on the Corruption Perceptions Index (161st out of 175) and Ibrahim Index of African Governance (44th out of 52, see Table 19.1). A recent UNESCO study has identified a correlation between low scientific productivity and ineffective governance (UNESCO, 2013).

Angola has the advantage of being minimally reliant on donor funding for its investment needs, being the second-largest oil producer in Africa after Nigeria and one of SADC's fastest-growing economies (see Figure 19.1). It ranks in the top half of SADC countries for GDP per capita and saw average annual growth of almost 3% over the period 2008–2013. Angola's income inequality is relatively low among SADC countries but it has a high poverty rate. It is deemed to have medium human development.

Table 20.5: **Status of national innovation systems in the SADC region**

Category	
Fragile	Democratic Republic of Congo, Lesotho, Madagascar, Swaziland, Zimbabwe
Viable	Angola, Malawi, Mozambique, Namibia, Seychelles, Tanzania, Zambia
Evolving	Botswana, Mauritius, South Africa

Note: National innovation systems can be analysed and categorized in terms of their potential to survive, grow and evolve. The assessment of viability thresholds is a complex exercise beyond the scope of the present chapter. The authors nevertheless propose the present set of three categories for a preliminary classification of national innovation systems in the SADC region. **Fragile systems** tend to be characterized by political instability, whether from external threats or internal political schisms. **Viable systems** encompass thriving systems but also faltering ones, albeit in a context of political stability. In **evolving systems**, countries are mutating through the effects of policy and their mutation may also affect the emerging regional system of innovation.

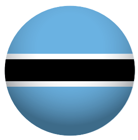
Source: elaborated by authors

There have been concerns over the environmental impact of oil exploration and extraction, particularly the effect of offshore drilling on the fishing industry. Combined with the uncertain sustainability of global oil prices and domestic stocks, not to mention the fact that the oil industry does not generate significant local employment, this concern led the government to create a Sovereign Wealth Fund in 2012 to invest profits from oil sales in the development of a number of local industries, in an effort to diversify the country's economy and spread prosperity (AfDB, 2013).

Full data on R&D expenditure are unavailable but there are few institutions performing research and the number of researchers is low. The country's KEI and KI values are the lowest among SADC countries. In 2011, the Ministry of Science and Technology published the *National Policy for Science, Technology and Innovation*. The policy sets out to organize and develop the national STI system, identify funding mechanisms and to harness STI to sustainable development.

The prolonged civil war (1975–2002) not only left higher education in a time warp but also caused many academics to emigrate. Since the end of the war, the number of universities has mushroomed from two (1998) to over 60 today with a student roll of more than 200 000. In 2013, the government launched *a National Plan for Training Professionals*. Moreover, in a bid to anchor higher education in its development efforts, Angola is hosting the Centre of Excellence for Science Applied to Sustainability, which was established in 2011 and received its first intake of students in 2013. The centre plans to produce 100 PhDs within a decade. The first of its kind in Africa, it provides research and training on sustainable development that is open to all Africans. The centre is located within the University of Agostinho Neto in Luanda (SARUA, 2012).

BOTSWANA



Good governance

Along with Tanzania, Botswana has one of the longest post-independence histories of political stability in Africa. A multiparty democracy, it is deemed the continent's best-performing country by the Corruption Perceptions Index (31st out of 175) and ranks third in Africa in the Ibrahim Index of African Governance (see Table 19.1). Real GDP per capita is relatively high and growing but the country nevertheless ranks second in the SADC for inequality and there is widespread poverty (Table 20.1). Botswana's incidence of HIV (18.5% of the population) is also among the highest in the world, according to the *Botswana AIDS Impact Survey* of 2013.

Botswana is the world's top producer of diamonds, in terms of value. Despite being heavily reliant on the mining sector, Botswana has escaped the 'resource curse' to a large extent by delinking public expenditure and revenue from the mining sector. This revenue is invested in a savings fund to enable an anti-cyclical fiscal policy. Revenue from diamonds has been invested in public goods and infrastructure and the government has long established universal scholarship schemes which fully subsidize education at all levels (AfDB, 2013).

Even before the slump in international demand during the global financial crisis of 2008–2009, diamond mining had been contributing less to economic growth with each plan period. This led the government to make diversifying the economy a priority of the *Tenth National Development Plan* for 2009–2016. The government considers private-sector participation as being 'critical' to the *Tenth Plan*'s success and enhancing the role of R&D as being the most effective way of fuelling entrepreneurship and private-sector growth (UNESCO, 2013).

In 2010, the government published its *Economic Diversification Drive*. A year later, it revised the Companies Act to allow applicants to register their company without the involvement of company secretaries, thereby reducing business start-up costs. The government has also introduced a points-based system to allow skilled expatriates to work in Botswana (UNESCO, 2013).

The centrepiece of the government's strategy is the development of six innovative hubs. The first of these was established in 2008 to foster the commercialization and diversification of agriculture. The second to be set up was the Botswana Diamond Hub. Until recently, rough diamonds accounted for 70% of Botswana's exports. After these exports contracted during the global financial crisis of 2008–2009, the government decided to derive greater benefits from its diamond industry by renegotiating agreements with multinational companies like De Beers in 2011 and setting up a Diamond Technology Park in Gaborone in 2009 as a hub for the local cutting and polishing of diamonds, as well as the manufacture of diamond jewellery. By 2012, the government had licensed 16 diamond polishing and cutting companies (UNESCO, 2013).

Hubs are also being put in place for innovation and the transport and health sectors. As of 2012, the Botswana Innovation Hub's governing bodies had approved and registered 17 entities that will operate in the park. These include academic institutions like the University of Botswana and companies active in such diverse areas as custom design and the manufacture of drilling rigs, specialized mining exploration technologies, diamond jewellery design and manufacturing, as well as ICT applications and software. By 2013, basic services had been installed on the 57-acre plot in Gaborone, such as water mains and electricity, and the site was ready for intensive development (UNESCO, 2013).

In addition, an education hub has been approved by the Government Implementation Co-ordinating Office, with the objective of developing quality education and research training to make Botswana a regional centre of excellence and promote economic diversification and sustainable growth. High unemployment (18.4% in 2013, see Table 20.1) has been linked to the mismatch between skills development and market needs, together with slow private-sector growth. The Botswana Education Hub will be co-ordinating its activities with those of the other five hubs in agriculture, innovation, transport, diamonds and health (UNESCO, 2013).

Botswana has two public and seven private universities. The University of Botswana is primarily a teaching institution, whereas the newly established Botswana International University of Science and Technology, which welcomed its first 267 students in September 2012, is R&D-based and determined to raise the academic qualifications of staff. There has been considerable progress in education over the past decade (SARUA, 2012). Scientific publications also increased from 133 to 210 between 2009 and 2014 (Figure 20.6).

The *National Policy on Research, Science, Technology and Innovation* (2011) is accompanied by an implementation plan (2012). The policy sets the target of raising the GERD/GDP ratio from 0.26% in 2012 to over 2% by 2016 (Republic of Botswana, 2011, p. 6). This target can only be reached within the specified time frame by raising public spending on R&D. The policy has four main thrusts:

- Development of a co-ordinated and integrated approach to STI planning and implementation;
- Development of STI indicators, in accordance with the guidelines of the OECD's *Frascati* and *Oslo Manuals*;
- The launch of regular participatory foresight exercises; and
- The strengthening of institutional structures responsible for policy monitoring and implementation.

The 2011 policy is a revision of the country's first *Science and Technology Policy* (1998). The 2011 policy has been consolidated with the 2005 *Botswana Research, Science and Technology Plan* (2005), following the recommendations of a review conducted by UNESCO in 2009. The main reason for the review was to align Botswana's policy with *Vision 2016* outlined in the *Tenth National Development Plan*. The review concluded that the same obstacles to R&D persisted in 2009, implying that the 1998 policy had made little impact on job and wealth creation (UNESCO, 2013).

In 2013, Botswana initiated the development of a *National Climate Change Strategy and Action Plan*. A climate change policy will be developed first, followed by the strategy. The process will reportedly be highly consultative, with the participation of rural inhabitants.

DEMOCRATIC REPUBLIC OF CONGO

A new academy of science and technology

The ongoing armed conflict in the Democratic Republic of Congo remains a major obstacle to the development of a national innovation system. The country shows the lowest HDI and GDP per capita and the highest poverty rate of any SADC member. The country's dependence on donor funding is high and climbed steeply between 2007 and 2009. The country also scores poorly (40th) in the Ibrahim Index of African Governance (see Table 19.1).

The Democratic Republic of Congo does not have a national STI policy. Scientific research capacity exists mainly in public universities and government-owned research institutes. The Ministry of Scientific Research and Technology supports five research organizations active in the fields of agriculture, nuclear energy, geology and mining, biomedicine, environment and conservation, as well as a geographical institute.

In 2012, the Academy for the Advancement of Science and Technology for Innovation was established in Kinshasa, driven by the community of researchers and financed by members' contributions, donations and legacies, with support from the Ministry of Scientific Research and Technology. Another sign of the scientific community's dynamism is the near-tripling of its research output between 2008 and 2014 (Figure 20.6).

The Democratic Republic of Congo has a relatively large higher education sector, with a total of 36 publicly funded universities, 32 of which were established between 2009 and 2012 (SARUA, 2012). There seems to be little interaction between universities and industry and, to date, a single business incubator has been established in the country.

The Academic Instruction Act (2011) has replaced the former policy framework for higher education dating from 1982. Another influential document is *Vision 2020*, which aims to develop a university curriculum attuned to national development priorities through three key strategies: the promotion of entrepreneurship, the development of technical and vocational skills and the provision of the relevant human capital through improved teacher training. The *Poverty Reduction Strategic Paper* of 2005 had articulated the need for teacher training and better vocational and technical skills and identified higher education as being a central player in meeting national development needs (AfDB *et al*., 2014).

LESOTHO

A compact to develop the private sector and social services

In mid-2014, this mountainous kingdom with a population of two million experienced a political crisis after parliament was suspended, prompting an attempted military coup. The SADC brokered a solution to the crisis which resulted in parliamentary elections being brought forward by two years to March 2015. The party of the outgoing prime minister was returned to power in what the SADC described as a 'free, fair and credible' election.

According to national figures, 62.3 % of the population lives below the national poverty line and unemployment is high, at 25.4% With 23% of 15–49 year-olds infected with HIV,[14] average life expectancy stands at less than 49 years. Human development is low, with Lesotho ranking 158th out of 187 countries in 2012, despite having registered some improvement since 2010 (Government of Lesotho and UNDP, 2014). GDP per capita grew by 18.7% over the period 2009–2013 (Table 20.2).

Three in four inhabitants live in rural areas and are dependent on subsistence agriculture. Since agricultural productivity is low and only 10% of the land is arable, Lesotho relies heavily on imports from South Africa. It also depends on its South African neighbour for employment and for the purchase of its main natural resource: water.

Within the country, the government remains the main employer and greatest consumer, accounting for 39% of GDP in 2013. Lesotho's largest private employer is the textile and garment industry; approximately 36 000 Basotho, mainly women, work in factories which produce garments for export to South Africa and the USA (see Figure 18.2). Diamond mining has grown in recent years and may contribute 8.5% to GDP by 2015, according to current forecasts. Lesotho remains extremely dependent on donor funding.

In 2007, Lesotho signed a six-year US$ 362.5 million Millennium Challenge Account Compact to strengthen the health care system, develop the private sector and broaden access to improved water supplies and sanitation. Thanks to Lesotho's 'strong performance' and 'continued commitment to democratic principles and good governance', the country became eligible in December 2013 to apply for a second compact[15] funded by the Millennium Challenge Account. The process of compact development takes two years, so, if the application is successful, the second compact will become effective in 2017.

14. See: www.unaids.org/en/regionscountries/countries/lesotho

15. See: www.lmda.org.ls

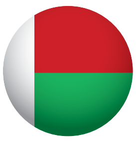
Major obstacles to economic growth, private sector-led entrepreneurship and poverty alleviation in Lesotho relate to the fact that the government has not managed to use its resources efficiently to provide public services that encourage high levels of private investment and entrepreneurship.

Much of STI policy still to be implemented

Lesotho's basic R&D indicators depict a poorly developed STI sub-sector with the lowest GERD/GDP ratio (0.01% in 2011) of any SADC country (Figure 20.3). The country has a single public university, the National University of Lesotho (est. 1945) and a number of other public and private tertiary-level institutions. The private establishments partly compensate for the limited capacity of the public sector to satisfy enrolment needs. Clearly, public resources need to be better utilized at all levels, if STI is to be harnessed to meeting the country's development needs.

The *National Science and Technology Policy* for 2006–2011 envisioned raising government funding of R&D to 1% of the annual national budget and recommended establishing new institutions, including the Lesotho Advisory Commission on Science and Technology to manage S&T policy implementation and the Lesotho Innovation Trust Fund to mobilize funding for STI. The Department of Science and Technology – located in the Ministry of Communications, Science and Technology – is responsible for promoting and co-ordinating STI policy, according to the detailed implementation plan developed in 2010. The plan required that measures be taken to ensure that all segments of society benefit from STI, in keeping with the Basotho spirit of *letsema*. However, to date, the policy remains largely unimplemented and has not been revised.

MADAGASCAR



A research policy oriented towards development

In Madagascar, the coup d'état of 2009 resulted in international sanctions which have curtailed donor funding. Today, the economy is faltering: GDP per capita dropped by 10.5% over the period 2008–2013. Madagascar has the second-highest reported poverty rate within the SADC after the Democratic Republic of Congo, even though it has a median ranking within the community for human development.

In terms of governance, Madagascar actually dropped from 118th to 127th place out of 175 countries between 2013 and 2014 in the Corruption Perceptions Index. All governance indices identify political instability as an aggravating factor for corruption – and vice versa – and as being the main obstacle to creating an enabling and healthy business environment (IFC, 2013). Like many countries, Madagascar observes International Anti-Corruption Day each year on 9 December. The theme in 2013 was 'Zero Corruption, 100% Development'.

Madagascar has a low GERD/GDP ratio (0.11% in 2011). R&D is spread across several research institutes which cover agriculture, pharmaceuticals, oceanography, environment, veterinary sciences, nuclear energy, botany and zoology, among other areas. The country counts six public universities and three technical universities, eight national centres of research and 55 privately funded universities and colleges. Enrolment has increased dramatically since 2005 and doctoral programmes are offered by 29 discipline-based schools or departments within both public and private universities.

The government has identified higher education as a major agent of national development. For example, Challenge 5 of the *Madagascar Action Plan* 2007–2012 identifies the need to transform higher education. Its specific goals are to:

- ensure competitiveness, creativity and the employability of graduates;
- foster research and innovation;
- offer diversified courses to meet national socio-economic needs;
- improve the governance of public universities; and
- develop high-quality private universities and technical institutes.

Between 2000 and 2011, the number of students enrolled in Madagascar's public universities more than doubled from 22 166 to 49 395, according to the Ministry of Education and Scientific Research. Nearly half attended the University of Antananarivo. The great majority of PhD students were enrolled in science and engineering disciplines (SARUA, 2012). The student population at both public and private universities almost doubled between 2006 and 2012 to 90 235 but the number of PhD candidates actually shrank (Table 19.4).

Madagascar does not have a national STI policy but it did adopt a national research policy in December 2013 to promote innovation and the commercialization of research results for socio-economic development. This policy is accompanied by five *Master Plans of Research* related to renewable energies, health and biodiversity, agriculture and food security, environment and climate change. These plans have been identified as priorities for R&D; other plans are being elaborated in 2015–2016.

Moreover, a Competitive Fund for Research and Innovation is currently being set up. It is intended to strengthen the relationship between research and socio-economic benefits and to throw bridges between public researchers and the private sector, as outlined by the national research policy. This fund is financed by the government, as well as by bilateral and multilateral partners.

In 2012, the Ministry of Higher Education and Scientific Research advocated a radical reform, emphasizing the importance of improving the interface between scientific research and the country's development goals.

MALAWI

Wooing investors to diversify the economy

Malawi has been a multiparty parliamentary democracy since 1994. For the past 10 years, the economy has grown annually by 5.6% on average, making it the sixth-fastest growing economy in the SADC. It is projected that, between 2015 and 2019, annual growth in real GDP will range from 6% to 5% (IMF, 2014). Malawi's ratio of donor funding to capital formation rose considerably over the period 2007–2012. At the same time, its attempts to diversify the agriculture sector and move up the global value chain have been seriously constrained by poor infrastructure, an inadequately trained work force and a weak business climate (AfDB *et al*., 2014).

Malawi has one of the lowest levels of human development in the SADC (see Tables 19.1 and 20.2) but it is also one of three African countries that 'are making especially impressive progress for several Millennium Development Goals,' along with Gambia and Rwanda, including with regard to primary school net enrolment (83% in 2009) and gender parity, which has been achieved at primary school level (UNESCO, 2014a).

The economy is heavily dependent on agriculture, which accounts for 27% of GDP (Figure 20.2) and 90% of export revenue. The three most important export crops are tobacco, tea and sugar – with the tobacco sector alone accounting for half of exports (see Figure 18.2). Malawi spends more on agriculture (as a share of GDP) than any other African country (see Table 19.2). Over 80% of the population is engaged in subsistence farming, with manufacturing earning just 10.7% of GDP (Figure 20.2). Moreover, most products are exported in a raw or semi-processed state.

Malawi is conscious of the need to attract more FDI to foster technology transfer, develop human capital and empower the private sector to drive economic growth. FDI has been growing since 2011, thanks to a government reform of the financial management system and the adoption of an *Economic Recovery Plan*. In 2012, the majority of investors came from China (46%) and the UK (46%), with most FDI inflows going to infrastructure (62%) and the energy sector (33%) [UNESCO, 2014a].

The government has introduced a series of fiscal incentives to attract foreign investors, including tax breaks. In 2013, the Malawi Investment and Trade Centre put together an investment portfolio spanning 20 companies in the country's six major economic growth sectors, namely agriculture, manufacturing, energy (bio-energy, mobile electricity), tourism (ecolodges) and infrastructure (wastewater services, fibre optic cables, etc.) and mining (UNESCO, 2014a).

In 2013, the government adopted a *National Export Strategy* to diversify the country's exports (Government of Malawi, 2013). Production facilities are to be established for a wide range of products[16] within the three selected clusters: oil seed products, sugar cane products and manufacturing. The government estimates that these three clusters have the potential to represent more than 50% of Malawi's exports by 2027 (see Figure 18.2). In order to help companies adopt innovative practices and technologies, the strategy makes provision for greater access to the outcome of international research and better information about available technologies; it also helps companies to obtain grants to invest in such technologies from sources such as the country's Export Development Fund and the Malawian Innovation Challenge Fund (Box 20.2) [UNESCO, 2014a].

Productive scientists, few university places

Despite being one of the poorest countries in the world, Malawi devoted 1.06% of GDP to GERD in 2010, according to a survey by the Department of Science and Technology, one of the highest ratios in Africa. Also noteworthy is that Malawian scientists publish more in mainstream journals – relative to GDP – than any other country of a similar population size (UNESCO, 2014a).

Enrolment in higher education struggles to keep up with rapid population growth. Despite a slight improvement, only 0.81% of the age cohort was enrolled in university by 2011. Moreover, although the number of students choosing to study abroad increased by 56% between 1999 and 2012, their proportion decreased from 26% to 18% over the same period (UNESCO, 2014a).

Malawi's first science and technology policy from 1991 was revised in 2002. Despite being approved, the 2002 policy has not been fully implemented, largely due to the lack of an implementation plan and an unco-ordinated approach to STI. This policy has been under revision in recent years, with UNESCO assistance, to re-align its focus and approaches with the second *Malawi Growth and Development Strategy* (2013) and with international instruments to which Malawi is a party (UNESCO, 2014a).

16. including cooking oil, soaps, lubricants, paints, animal feed, fertilizers, snacks and cosmetics

The *National Science and Technology Policy* of 2002 envisaged the establishment of a National Commission for Science and Technology to advise the government and other stakeholders on science and technology-led development. Although the Science and Technology Act of 2003[17] made provision for the creation of this commission, it only became operational in 2011, with a secretariat resulting from the merger of the Department of Science and Technology and the National Research Council. The Secretariat of the National Commission for Science and Technology reviewed the current *Strategic Plan for Science, Technology and Innovation (2011–2015*) but, as of early 2015, the revised STI policy had not yet met with Cabinet approval (UNESCO, 2014a).

Among the notable achievements stemming from the implementation of national STI policies in recent years are the:

- establishment, in 2012, of the Malawi University of Science and Technology and the Lilongwe University of Agriculture and Natural Resources (LUANAR[18]) to build STI capacity. This brings the number of public universities to four, with the University of Malawi and Mzuzu University;
- improvement in biomedical research capacity through the five-year Health Research Capacity Strengthening Initiative (2008–2013) awarding research grants and competitive scholarships at PhD, master's and first degree levels, supported by the UK Wellcome Trust and DfID;
- strides made in conducting cotton confined field trials, with support from the US Program for Biosafety Systems, Monsanto and LUANAR (see Box 18.2).
- introduction of ethanol fuel as an alternative fuel to petrol and the adoption of ethanol technology;
- launch of the *ICT Policy for Malawi* in December 2013, to drive the deployment of ICTs in all economic and productive sectors and improve ICT infrastructure in rural areas, especially via the establishment of telecentres; and
- a review of secondary school curricula in 2013.

17. A Science and Technology Fund was also established by the Science and Technology Act of 2003 to finance research and studies through government grants and loans; it was not yet operational by 2014 (UNESCO, 2014b).

18. LUANAR was delinked from the University of Malawi in 2012.

MAURITIUS

Competing with South Africa as an investment hub

Mauritius is a small island nation with 1.3 million inhabitants. Unemployment is low and the country counts the second-highest GDP per capita in the SADC; it grew by more than 17% over the period 2008–2013. Mauritius also ranks second-highest in the SADC region for human development and has the third-best score in the Corruption Perceptions Index (47th out of 175), behind Botswana (31st) and Seychelles (43rd). In 2012, there were almost twice as many students enrolled in higher education as in 2006 (Table 19.4).

The economy is driven by tourism, textile manufacturing, sugar and financial services. There has been a rapid diversification of the economic base towards ICTs, seafood, hospitality, property development, health care, renewable energy, education and training, which have attracted both local and foreign investors. Mauritius' status as an investment hub for new businesses has also provided significant opportunities for offshore companies. This diversification is largely due to the government's determination to move the economy up the value chain towards an economy based on high skills and technology. The strategy has worked: in 2013, Mauritius overtook South Africa to become the most competitive economy in sub-Saharan Africa.

Box 20.2: **The Malawi Innovation Challenge Fund**

The Malawi Innovation Challenge Fund (MICF) is a new competitive facility, through which businesses in Malawi's agricultural and manufacturing sectors can apply for grant funding for innovative projects with potential for making a strong social impact and helping the country to diversify its narrow range of exports.

The fund is aligned on the three clusters selected within the country's *National Export Strategy*: oil seed products, sugar cane products and manufacturing.

The MICF provides a matching grant of up to 50% to innovative business projects to help absorb some of the commercial risk in triggering innovation. This support should speed up the implementation of new business models and/or the adoption of technologies.

The first round of competitive bidding opened in April 2014.

The fund is endowed with US$ 8 million from the United Nations Development Programme and the UK Department for International Development.

Source: AfDB press release and personal communication; authors

To a large extent, the radical transformation of the Mauritian economy has been informed by a policy document entitled *Maurice Ile Durable (Mauritius: Sustainable Island)*, adopted in 2011. This document anchors economic development firmly in sustainability and has five interlinking foci: energy, the environment, education, employment and equity. Mauritius passed an Energy Efficiency Act in 2011 and has adopted an *Energy Strategy for 2011 –2025* which stresses sustainable building design and transportation, together with the development of renewable energy sources such as solar, geothermal and hydropower.

Mauritius has been a central player in the implementation of the *Programme of Action for the Sustainable Development of Small Island Developing States*, having hosted one of the three landmark meetings[19] which are driving this programme, in 2005. Mauritius led a call, in 2014, for the establishment of a UNESCO centre of excellence on ocean science and innovation for capacity-building and research, as a contribution to the *2030 Agenda for Sustainable Development*. The call was endorsed by the *Mauritius Ministerial Declaration* adopted by Mauritius, Comoros, Madagascar and the Seychelles at the conclusion of a high-level meeting on strengthening STI policy and governance for the sustainable development of small island developing states and their resilience to climate change.

A series of moves to boost R&D

In 2012, Mauritius devoted 0.18% of GDP to GERD (Figure 20.3). About 85% of public R&D expenditure is invested in S&T-related fields. The sectors with the highest expenditure (together accounting for about 20% of total spending on S&T) are agriculture, environment and ocean/ marine sciences, followed by health and ICTs, which account for about 4–7% of total spending. Mauritius has set itself the target of increasing public expenditure on R&D to 1% of GDP by 2025 and expects the private sector to contribute at least 50% of national expenditure on R&D by this date.

In 2009, the Mauritius Research Council held a series of consultations. In addition to its advisory role, this government agency co-ordinates and funds research to give industries the edge in innovation. The consultations produced the following proposals for:

- raising private spending on R&D;
- strengthening intellectual property laws;
- promoting market-driven research;
- consolidating the linkages between researchers in the public sector and industry; and
- instituting fiscal measures to attract private investment in R&D.

In response to these recommendations, the government took a series of measures to boost R&D, including the:

- provision, in 2014, of Rs 100 million (*circa* US $3 million) to fund R&D, including through the Public Sector Collaborative Research Scheme and the Small Business Innovation Scheme, operated by the Mauritius Research Council; the main project areas are: biomedicine; biotechnology; energy and energy efficiency; ICTs; land and land use; manufacturing technology; science and technology education; social and economic research; and water resources;
- amendment, in 2014, to the Mauritius Research Council Act to provide for a National Research and Innovation Fund;
- establishment of the International Institute of Technology Research Academy, which moved to its main campus in 2015, through a memorandum of understanding between the Indian Institute of Technology in India and the Mauritius Research Council, in collaboration with the University of Mauritius; and, lastly,
- provision, in 2013, for the recruitment of 30 experienced international lecturers for the country's two universities – the University of Mauritius and the University of Technology[20] – to foster greater research and improve teaching standards.

The Mauritius Research Council is the main co-ordinating agency of the Ministry of Tertiary Education, Science, Research and Technology. The ministry is currently overseeing the formulation of the country's first *National Policy and Strategy on Science, Technology and Innovation* covering the period from 2014 to 2025. The main foci of the draft policy are:

- human competencies in the STI sector;
- the role of the public research sector;
- the link between science and society;
- technology absorption and innovation;
- investment in research and innovation;
- meeting challenges through enhanced research;
- promotion of African STI initiatives; and
- governance and sustainability.

Some challenges remain for policy formation; there is a need to bring coherence and a long-term vision to the forefront of STI governance and to bridge the gap between public research institutions and private businesses.

19. First adopted in Barbados in 1994, this programme was updated in Mauritius in 2005 then again in Samoa in 2014.

20. Three other institutions offer higher education: the Mauritius Institute of Education, the Mahatma Gandhi Institute and the Mauritius College of the Air.

MOZAMBIQUE

An opportunity to accelerate development

Mozambique's high growth rate over the past decade (6.0–8.8% per year) dates from the start of aluminium and natural gas production in the 2000s, which brought in substantial FDI. The country's reliance on donor funding, while still high, decreased dramatically between 2007 and 2012. However, economic growth has not yet translated into human development. Mozambique still ranks 185th out of 187 countries, there having been no change since 2007. Poverty is widespread. This situation is a major obstacle to economic diversification, especially when combined with high financial costs, poor infrastructure and an inhibitive regulatory framework (AfDB, 2013). Mozambique also scores poorly on the Corruption Perceptions Index (119th out of 175) and the Ibrahim Index of African Governance (see Table 19.1).

Neither the country's *Science and Technology Policy* (2003), nor the *Mozambique Science, Technology and Innovation Strategy,* approved in 2006 with a horizon of 10 years, has yet delivered on its promises. The *Strategy* establishes a set of priorities to eradicate extreme poverty, harness economic growth and improve the social well-being of all Mozambicans. It is being implemented in conjunction with international partners. The GERD/GDP ratio (0.42% in 2010) for Mozambique places it in the middle range of SADC countries but the density of researchers is low: just 66 per million inhabitants in 2010 (head count), excluding the business sector.

To foster implementation of the *Science and Technology Policy,* Mozambique created a National Research Fund in 2006 that is operated by the Ministry of Science and Technology. Funding goes to numerous projects for scientific research, innovation and technology transfer in the following areas: agriculture, education, energy, health, water, mineral resources, environmental sustainability, fisheries and marine sciences and botanical sciences.

The country has 16 research institutions, in addition to several national research councils active in the fields of water, energy, agriculture, medicine and ethno-botany, among others. The National Academy of Science dates from 2009.

Mozambique has 26 institutions of higher education, half of which are privately run. However, public institutions account for the majority of students, particularly Eduardo Mondlane University and Universidade Pedagogica. Demand for higher education is growing rapidly: there were four times more students enrolled in 2012 (124 000) than in 2005 (see Table 19.4).

Like several of its neighbours, Mozambique is currently mapping its science system, in partnership with UNESCO's Global Observatory of STI Policy Instruments (GO→SPIN).

The ultimate aim is to use this mapping exercise as the basis for drawing up a revised STI policy that could be applied to such critical areas as mitigating the consequences of climate change; exploring new energy sources; generating innovation to foster social inclusion; promoting the sustainable management and conservation of freshwater; terrestrial resources and biodiversity; and disaster resilience.

With its newfound political stability and income from aluminium, gas and coal, Mozambique has an unprecedented opportunity to accelerate development and improve social welfare. To generate income in a sustainable way, however, wealth must be managed and transformed into assets that can continue to serve the country's long-term interests.

NAMIBIA

A need to diversify the economy

While Namibia is classified as a middle-income country on the basis of its GDP per capita, its Gini coefficient (see the glossary, p. 738) reveals one of the world's highest levels of inequality, despite a modest improvement since 2004. Namibia also suffers from an unemployment rate of 16.9 % (Table 20.1) and widespread poverty, with the majority of the population surviving on subsistence agriculture. To this must be added the impact of long periods of severe drought and a high prevalence of HIV and AIDS. Namibia also ranks 128th out of 186 countries for human development. These indicators point to the formidable obstacles that Namibia must overcome, if it is to shake off its over-reliance on mining (see Figure 18.2), which only employs about 3% of the population.

Namibia's long-term development strategy is guided by *Vision 2030,* a planning document adopted in 2004 to 'reduce inequalities and move the nation significantly up the scale of human development, to be ranked high among the developed countries[21] in the world.' Five 'driving forces' were identified to realize the objectives of *Vision 2030*: education, science and technology; health and development; sustainable agriculture; peace and social justice; and gender equality.

In 2010, Namibia still had a low GERD/GDP ratio (0.14%) but it did count 343 researchers (head count) per million inhabitants, one of the region's better ratios. The country's KEI and KI values are also quite high, even though Namibia dropped nine places between 2000 and 2012. Two factors no doubt explain this relatively good performance: Namibia's market-friendly environment, which benefits from its proximity to South Africa; and its two reputable universities which have produced a critical mass of skilled workers over the past two decades, as well as a small, well-trained professional and managerial class.

21. See: www.gov.na/vision-2030

Two reputable universities

Taken together, the Namibia University of Science and Technology (formerly the Polytechnic of Namibia) and the University of Namibia account for 93% of student enrolment, the remainder being assured by two private institutions.

The University of Namibia boasts a student population of about 19 000 and a network of 12 satellite campuses and 9 regional centres nationwide. It has Faculties of: Agriculture and Natural Resources; Economics and Management Science; Education; Engineering; Health Sciences; Humanities and Social Sciences; Law; and Natural Sciences. The university offers 12 PhD programmes and has so far awarded 122 PhDs. It has put incentives in place to encourage researchers to publish their findings.

The Namibia University of Science and Technology strives to 'enhance innovation, entrepreneurship and competitiveness in Namibia and the SADC region.' It counts seven schools/ faculties and 10 centres of excellence, which served a student body of over 12 000 in 2014. A Cooperative Education Unit (CEU) was established in 2010, in order to give graduates the skills required by industry. The CEU collaborates with industry in the design of its curricula and co-ordinates a programme through which students compete for an internship or industrial placement to put what they have learned into practice.

A three-year programme to boast STI

Within the Ministry of Education, it is the Directorate for Research, Science and Technology under the Department of Tertiary Education, Science and Technology which ensures co-ordination of science. In 2013, Namibia established a National Commission on Research, Science and Technology, pursuant to the Research, Science and Technology Act (2004). The commission is mandated to implement the Biosafety Act of 2006. It has also been entrusted with developing a three-year National Research, Science, Technology and Innovation Programme, with UNESCO's[22] assistance. The programme stems from the directives of the *National Policy on Research, Science and Technology*, adopted in 1999.

A national consultative workshop was held in March 2014 to pave the way towards an implementation strategy for the National Research, Science, Technology and Innovation Programme. Participating researchers, innovators and entrepreneurs assisted in identifying national priority fields, taking into consideration *Namibia's Industrial Policy* (2013), its current economic blueprint, the *Fourth National Development Plan* (2012–2017) and *Vision 2030*. The programme will seek to create an environment more conducive to research and innovation in the essential areas of policy, human resource development and the related institutional framework.

In 2013, UNESCO helped Namibia to develop a manual for operationalizing the National Research, Science and Technology Fund. The first disbursement from the fund was made jointly with South Africa in March 2014 (30 projects for a value of N$ 3 million, *circa* US$ 253 000). This was followed by a first national disbursement in May 2014 (27 projects for N$ 4 million). The funds from the second and third national calls for research proposals are due to be disbursed in May 2015. The grant recipients thus far are the University of Namibia, Polytechnic of Namibia, Ministry of Fisheries and Marine Resources, Ministry of Education and an NGO, the Desert Research Foundation of Namibia.

Namibia is also participating in UNESCO's GO→SPIN programme, in order to put a reliable information system in place to monitor STI policy implementation.

SEYCHELLES

A first university and national STI institute

Having recovered from virtual economic collapse in 2007–2008, Seychelles is now a rising star (AfDB *et al*., 2014). It comes out on top in the SADC region for GDP per capita, human development and unemployment and poverty levels. It is also one of the top-scorers for good governance, low corruption and general security. Despite these achievements, not everyone in this small island state is seeing the benefits. The economy is primarily based on tourism, agriculture and fisheries but economic growth has been led almost exclusively by the tourism sector. As a result, Seychelles has the greatest level of inequality of any SADC country.

There are no recent R&D data for Seychelles. In 2005, the country had a low GERD/GDP ratio (0.30%) and, given its population of 93 000, only a handful of researchers: 14. The main research institute is the Seychelles Centre for Marine Research and Technology (est. 1996).

Seychelles' first university dates only from 2009; it welcomed its first 100 students in 2012 (see Table 19.4). Though still in its infancy, the University of Seychelles is developing rapidly. It has already established strong collaboration with other universities in the SADC region (SARUA, 2012).

Parliament passed a bill creating the country's first National Institute of Science, Technology and Innovation in 2014. In January 2015, the government upgraded the Department of Entrepreneurship Development and Business Innovation to ministry status, adding the portfolio of investment.

22. See: http://tinyurl.com/unesco-org-policy-namibia

SOUTH AFRICA

Outward FDI flows have doubled

South Africa is currently Africa's second-largest economy after Nigeria. Despite having a population of only 53 million, it generates about one-quarter of African GDP. It is classified as a middle-income country and has a relatively solid national innovation system. With its regional political influence and growing economic presence in Africa, the country has the potential to drive economic growth across the continent. For the moment, its weight is felt most by its immediate SADC neighbours, through the development of trading partnerships, political agreements, business linkages and movements of people.

South Africa is the main destination for FDI inflows to the SADC region, attracting about 45% of the region's FDI in 2013, a slight decrease from 48% in 2008. South Africa is also establishing itself as a main investor in the region: over the same six-year period, its outward flows of FDI almost doubled to US$ 5.6 billion, powered by investment in telecommunications, mining and retail in mostly neighbouring countries. In 2012, South Africa invested in more new FDI projects in Africa than any other country in the world. Moreover, among emerging economies, it is the second-biggest investor in least developed countries after India, according to the United Nations Conference on Trade and Development.

Through the Department of Science and Technology, South Africa has entered into 21 formal bilateral agreements with other African countries in science and technology since 1997, most recently with Ethiopia and Sudan in 2014 (Table 20.6). Within three-year joint implementation plans which define spheres of common interest, co-operation tends to take the form of joint research calls and capacity-building through information- and infrastructure-sharing, workshops, student exchanges, development assistance and so on.

A negative trade balance in high-tech

South Africa trades mainly with Botswana (21%), Swaziland, Zambia and Zimbabwe (12% each) and Angola (10%). This contrasts with the main destinations for South African FDI, which are Mauritius (44 %), Tanzania (12%) and Mozambique (7%). Table 20.7 shows that South Africa has a consistently high negative trade balance in high-tech products, along with the rest of the SADC economies, making it a peripheral national innovation system in the global arena.

STI to help diversify the economy by 2030

The vision of the *National Development Plan* (2012) is for South Africa to become a diversified economy firmly grounded in STI by 2030. This transition is guided by the *Ten-Year Innovation Plan* (2008–2018) and its five 'grand challenges': biotechnology and the bio-economy (formerly pharmaceuticals); space; energy security; global change; and understanding of social dynamics. Among the achievements so far, we could cite:

- the decision in 2012 to host the € 1.5 billion project to build the world's largest radio telescope in South Africa and Australasia; this is bringing significant opportunities for research collaboration (see Box 20.3), attracting leading astronomers and researchers at all stages of their careers to work in Africa; it is worth noting that South African astronomers co-authored 89% of their publications with foreign collaborators during 2008–2014;
- the *National Bio-economy Strategy*, approved in 2013, which positions bio-innovation as an essential tool for reaching the country's industrial and social development goals;
- within the DST, a reorganization of some programmes in the past five years to give greater emphasis to innovation that addresses social challenges; the Socio-Economic Innovation Partnerships programme within DST is responsible for the downstream innovation chain, through sub-programmes on innovation for inclusive development and the green economy, among others;
- the launch of the DST Technology Top 100 internship programme in 2012, which places unemployed science, technology and engineering graduates in high-tech companies; in 2013 and 2014, one in four of the 105 interns were offered permanent employment with their host companies at the end of the one-year programme; in 2015, a further 65 candidates were placed with companies in the Gauteng and Western Cape Provinces; it is planned to expand the network of private firms involved in the programme.

A fund to boost sagging private sector R&D

South Africa's GERD/GDP ratio (0.73% in 2012) has dropped from a high of 0.89% in 2008. This has been mostly due to a sharp drop in private sector R&D, in spite of rising public spending on R&D. However, South Africa's research output still comprises about 85% of Southern Africa's total output (Lan *et al.*, 2014).

To help reach the target of a GERD/GDP ratio of at least 1%, the Sector-Specific Innovation Fund was launched in 2013. This fund targets specific industrial sectors, which partner with the government through the DST to support the industry's specific research, development and innovation needs, through a co-funding arrangement. This funding instrument also addresses one of the recommendations from the 2012 *Ministerial Review Report*, which called for greater interaction between DST and the private sector.

The R&D tax incentive programme introduced in 2007 and amended in 2012 gives a 150% tax deduction for expenditure on eligible scientific or technological R&D undertaken by

Table 20.6: **South Africa's bilateral scientific co-operation in Africa, 2015**

Joint co-operation agreement (signed)	Human development	Intellectual property	STI policy	Biosciences	Biotechnology	Agriculture /Agro-processing	Space	Laser technology	Nuclear medical technology	Water management	Mining / Geology	Energy	ICTs	Mathematics	Environment and climatechange	Indigenous knowledge	Aeronautics	Material sciences and nanotechnology	Basic sciences	Human and social sciences
Algeria (1998)								●	●								●	●		
Angola (2008)	●																			
Botswana (2005)*					●	●	●			●	●	●	●			●				
Egypt (1997)							●	●										●		●
Ethiopia (2014)																				
Ghana (2012)**					●		●						●							
Kenya (2004)*						●	●						●							
Lesotho (2005)						●														
Malawi (2007)	●		●	●				●								●				
Mali (2006)																				
Mozambique (2006)**	●					●	●						●							
Namibia (2005)*						●	●				●		●			●				
Nigeria (2001)					●		●				●							●		
Rwanda (2009)				●			●					●			●				●	
Senegal (2009)																				
Sudan (2014)																				
Tanzania (2011)		●	●		●								●					●		
Tunisia (2010)					●							●	●							
Uganda (2009)				●			●					●		●	●	●				
Zambia (2007)*							●				●		●			●				
Zimbabwe (2007)	●				●						●		●					●		

*partner of the African Very Long Baseline Interferometry Network and of the Square Kilometre Array
**partner of the African Very Long Baseline Interferometry Network

Source: compiled by authors via the DST

enterprises or individuals. The 2012 amendment requires companies to apply for pre-approval of their R&D projects in order to qualify. The programme has grown over the past eight years and has provided tax reductions to nearly 400 claimants, nearly half of which are small and medium-sized enterprises. The programme has managed to leverage more than ten times the value in R&D from a R 3.2 billion government contribution to this incentive.

The earlier DST Innovation Fund (1999) has been transformed into a range of funding instruments grouped under the Technology Innovation programme administered by the Technology Innovation Agency, which has been operative since 2010. Some of the most recently launched funds include the Youth Technology Innovation Fund (2012) targeting innovators between the ages of 18 and 30 who receive vouchers enabling them to access services and/or resources that they could not otherwise afford, and a Seed Fund (2012) to assist universities in bridging financing requirements, in order for them to translate university research output into ideas that can be commercialized.

The Technology and Human Resources for Industry (THRIP) scheme matches investment by industry in projects where researchers from public institutions, including universities, serve as project leaders and students are trained through projects in industry. THRIP was established in 1994 and was the object of an external evaluation in 2013; this was followed by a review of some THRIP processes that has been dubbed the 're-invigoration of THRIP'. This review led to a series of new measures, including the provision of student bursaries for the first time and the introduction of a 'first-come-first-served' rule to accelerate the uptake of awarded funds. From 2010 to 2014, THRIP supported an average of 1 594 students and 954 researchers per year, showing steady growth in the numbers of black and female researchers over the years.

An older scheme which has helped to increase the number of black and female researchers is the South African Research Chairs Initiative (SARChI) established in 2006. SARChI was externally reviewed in 2012 and, by 2014, had awarded a total of 157 chairs. The Centres of Excellence funding scheme launched in 2004 currently has a network of 15 research centres, five of which were established in 2014. One of the most recent is the Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy, the work of which is expected to lead to better decision-making in STI policy and consolidate related national information systems.

The *National Development Plan* (2012) has fixed a target of producing 100 000 PhDs by 2030 to improve the country's capacity for research and innovation. The DST has significantly increased its funding for postgraduate students. By 2014, 34 PhDs were being produced per million inhabitants but this is still below the target of 100 PhDs per million inhabitants fixed by the *Plan*.

Table 20.7: **International trade by the SADC in high-tech products, 2008–2013, in US$ millions**

	TOTAL											
	Import						Export					
	2008	2009	2010	2011	2012	2013	2008	2009	2010	2011	2012	2013
Botswana	251.7	352.9	248.0	274.1	303.7	–	21.1	24.4	15.1	44.6	62.7	–
Lesotho	16.6	28.4	–	–	–	–	0.4	1.6	–	–	–	–
Madagascar	254.1	151.8	177.0	141.6	140.2	–	7.4	10.7	5.5	52.6	2.0	...
Malawi	112.5	148.9	208.3	285.4	–	152.4	1.7	3.4	2.0	22.7	–	11.0
Mauritius	284.3	327.8	256.6	255.2	344.8	343.5	101.1	21.9	6.2	9.8	10.6	6.3
Mozambique	167.3	148.6	125.4	134.1	189.2	1 409.2	6.1	23.8	0.5	71.2	104.7	82.1
Namibia	199.5	403.8	334.9	401.9	354.6	378.9	22.0	42.8	49.3	46.6	108.0	71.7
Seychelles	32.1	–	–	–	–	–	0.2	–	–	–	–	–
South Africa	10 480.4	7 890.5	10 190.3	11 898.9	10 602.2	11 170.9	2 056.3	1 453.3	1 515.6	2 027.3	2 089.1	2 568.6
Tanzania	509.1	532.2	517.4	901.7	698.4	741.6	11.8	18.1	27.4	43.0	98.9	50.0
Zambia	209.7	181.9	236.4	354.9	426.7	371.2	8.8	5.9	4.6	222.0	55.2	40.0
Zimbabwe	116.8	201.1	393.3	343.1	354.2	447.3	80.0	7.3	9.2	9.7	20.4	18.5

Note: Rankings are for a total of 145 countries.

Source: World Bank

Box 20.3: **South Africa wins bid to host radio telescope**

In 2012, South Africa and Australia won a bid to build the world's largest radio telescope, the Square Kilometre Array (SKA), at a cost of € 1.5 billion. As a result, South Africa will work with eight African partners, six of them from within the SADC: Botswana, Madagascar, Mauritius, Mozambique, Namibia and Zambia. The other two are Ghana and Kenya.

South Africa is also co-operating with other SADC countries in skills training, through the African SKA Human Capital Development Programme, which has been operating since 2005. In 2012, the programme awarded about 400 grants for studies in astronomy and engineering from undergraduate to postdoctoral level, while also investing in training programmes for technicians. Astronomy courses are being taught as a result of the SKA Africa project in Kenya, Madagascar, Mauritius and Mozambique.

This work is complemented by an agreement signed in 2009 between Algeria, Kenya, Nigeria and South Africa for the construction of three low-Earth-orbiting satellites within the African Resource Management Constellation (ARMC). South Africa will build at least one out of the three, construction of which (ZA-ARMC1) began in 2013.

The development of qualified personnel and researchers is a critical prerequisite for the successful implementation of the SKA project in South Africa and the construction of new satellites under the ARMC agreement. These initiatives will develop Africa's technological and human capacities in Earth observation, for use in urban planning, land cover mapping, disaster prediction and monitoring, water management, oil and gas pipeline monitoring and so on.

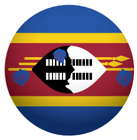
Source: compiled by the authors

A popular destination for scientists and students

Within the SADC, South Africa hosts the largest number of leading scientists, consistent with its leading role in African science. Southern Africa is known for its unhindered circulation of scientific personnel and research mobility, with South Africa playing an important role as a hub for higher education and research in the region. Nearly half of the researchers in South Africa (49%) are transitory, spending fewer than two years in the country's research centres (Lan *et al.,* 2014).

South African universities attracted 61 000 foreign African students in 2009, providing potential human capital for South Africa and facilitating a greater integration with the rest of the continent (UIS, 2012). Students from SADC countries pay the same fees as local students. This is in accordance with the *SADC Protocol on Education and Training* and effectively means that the South African taxpayer subsidizes their studies. Other initiatives, such as the African Institute for Mathematical Sciences (AIMS), further encourage the circulation of students, scientists and researchers in the region and beyond (Box 20.4).

SWAZILAND



STI development undermined by social problems

The Kingdom of Swaziland is the second-smallest country in Southern Africa after the Seychelles, with a population of less than 1.3 million. In spite of being classified as a lower middle-income country, Swaziland shares characteristics with Africa's low-income countries. About 78% of the population derives its livelihood from subsistence agriculture and 63% lives in poverty that is exacerbated by regular food shortages. Unemployment has remained high over the past decade, at about 23% (Figure 20.1). There is also a high prevalence of HIV and AIDS: 26% among the adult population.

The ratio of donor funding to capital formation is high but fell considerably over 2007–2009. Economic growth has been sluggish for over a decade, hovering between 1.3% and a high of 3.5% in 2007. In 2011, the country even slipped into recession (-0.7%). GDP per capita is nevertheless situated at the higher end of the SADC scale (Table 20.1). The economy is closely tied to that of neighbouring South

Box 20.4: A network of African Institutes for Mathematical Sciences

The African Institute for Mathematical Sciences (AIMS) is a pan-African network of centres of excellence for postgraduate education, research and outreach in mathematical sciences. The first AIMS institute was founded in Cape Town (South Africa) in 2003.

Four other institutes have since been set up in Senegal (2011), Ghana (2012), Cameroon (2013) and Tanzania (2014). That in Senegal proposes courses in both French and English. So far, these five institutes have produced 731 graduates, one-third of whom are women.

The institutes teach both basic and applied mathematics, covering a large range of mathematical applications in physics (including astrophysics and cosmology), quantitative biology, bioinformatics, scientific computing, finance, agriculture modelling and so on.

The institute in Cape Town was set up with the support of six universities which continue to contribute to the academic programme: Cambridge and Oxford (UK), Paris Sud XI (France) and Cape Town, Stellenbosch and Western Cape (South Africa).

In addition to its academic programmes, AIMS South Africa has a research centre in interdisciplinary areas like cosmology, computing and finance. The institute also directs the AIMS Schools Enrichment Centre for primary and secondary school teachers, which also organizes public lectures, workshops and master classes and supports maths clubs in schools across the country.

The other AIMS institutes also provide community services. AIMS Senegal has developed an innovative teaching module for secondary school maths teachers and has partnered with local businesses to raise funds for the creation of a national contest on computer applications and mathematical modelling, with a focus on finding development-oriented solutions. Scholars and lecturers from AIMS Ghana have equipped teachers at Biriwa Junior High School with an innovative teaching module. AIMS Cameroon is planning to launch its own research centre to host resident and visiting researchers from universities in Cameroon and beyond.

AIMS is the brainchild of South African cosmologist Neil Turok, whose family had been exiled for supporting Nelson Mandela during the Apartheid years. Knowing Mandela's passion for education, Turok had no difficulty persuading him to endorse the project.

After AIMS South Africa won the TED Prize in 2008, Turok and his partners developed the AIMS Next Einstein Initiative, the goal of which is to build 15 centres of excellence across Africa by 2023. The Government of Canada made a US$ 20 million investment in 2010, through its International Development Research Centre, and numerous governments in Africa and Europe have followed suit.

The plan for a vast network is gathering momentum. In October 2015, a forum is taking place in Dakar under the auspices of UNESCO's International Basic Sciences Programme to take the project to the next stage.

Source: www.nexteinstein.org; Juste Jean-Paul Ngome Abiaga, UNESCO

Africa for trade and its currency is pegged on the South African rand.

Nine out of ten adults are literate, one of the continent's highest ratios. By 2010, the Orphaned and Vulnerable Children's Initiative launched in 2002 and the State Funded Primary Education Programme (2009–2013) had together contributed to a 10% increase in primary school enrolment, which stood at 86%.

Swaziland has four universities and five colleges. However, only the University of Swaziland can claim to have research centres and institutes, such as the Swaziland Institute for Research in Traditional Medicine, Medicinal and Indigenous Food Plants.

In 2012, public expenditure on education accounted for 7.8% of GDP. Although only 13% of this went to higher education, this still represents a healthy investment of 1% of GDP (see Table 19.2). Although education remains the top priority, government spending on education has since become a casualty of the poor economic situation.

Enrolment in higher education remains low but is progressing: there were 8 057 tertiary students in 2013, up from 5 692 seven years earlier (see Table 19.4). One key development has been the introduction of PhD programmes in recent years, including one in agriculture at the University of Swaziland since 2012. Some 234 students were enrolled in PhD programmes in 2013.

A survey conducted by the UNESCO Windhoek Office in 2008 found that the University of Swaziland had the highest concentration of researchers, followed by the Energy Department of the Ministry of Natural Resources and Energy and the Agricultural Research Division of the Ministry of Agriculture. Some industries and public enterprises also engage in sporadic research (SARUA, 2009). Swaziland scores highly on the KEI and KI index, despite having dropped nine places between 2000 and 2012.

STI is acknowledged as being a top national priority in the *National Science, Technology and Innovation Policy,* which was drawn up in 2011 but has yet to be approved by parliament. UNESCO has been accompanying this process since 2008, when it prepared a status report of STI in Swaziland at the Ministry of Education's behest. The process has spawned the development of a *National Science, Mathematics and Technology Education Policy*, implemented by the Ministry of Education and Training. A Royal Science and Technology Park is also currently under construction, funded jointly by the Government of Swaziland and Chinese Taipei.

In November 2014, a Directorate for Science, Technology and Innovation was established within the Ministry of Information, Communication and Technology. The directorate is responsible for finalizing the *National Science, Technology and Innovation Policy*. A National Commission for Research, Science and Technology is also being established to replace the existing National Research Council.

Funding instruments such as venture capital and tax relief for R&D are non-existent in Swaziland, as donors have tended to focus on providing aid. The draft STI policy acknowledges the need to develop a diverse range of financial instruments and funding bodies to stimulate innovation.

UNITED REPUBLIC OF TANZANIA

Consistently high economic growth

Tanzania's socialist model of economic development was supplanted in the early 1990s by a multiparty parliamentary democracy which has ensured political stability ever since. An economic adjustment programme launched in the 1990s reduced state economic controls and nurtured the private sector; supported by the World Bank, the IMF and bilateral donors, this programme has contributed to average annual economic growth in Tanzania of between 6.0% and 7.8% since 2001 (Pahlavan, 2011). Though still high, donor funding dropped substantially between 2007 and 2012. As the economy becomes less reliant on donor funding, it may gradually diversify.

So far, impressive growth has not significantly altered the country's economic structure, which is still based on agriculture. The latter accounted for 34% of GDP in 2013, compared to 7% for manufacturing. GDP per capita remains low by SADC standards but nevertheless progressed between 2009 and 2013 (Table 20.2). Tanzania is also a member of the East African Community (see Chapter 19), with which its trade more than doubled between 2008 and 2012 (AfDB *et al*., 2014).

Tanzania's low level of human development has improved somewhat in recent years. The country has the lowest level of income inequality within the SADC and little unemployment (just 3.5%) but its poverty rate is the highest among SADC countries with viable national innovation systems.

Policies to harness STI to development

The *Vision 2025* document adopted in 1998 aspires to 'transform the economy into a strong, resilient and competitive one, buttressed by science and technology'. Tanzania's first *National Science and Technology Policy* (1996) was revised in 2010 and renamed the *National Research and Development Policy*. The policy recognizes the need to improve the process of prioritization of research capacities, international co-operation in strategic R&D areas and planning for human resources; it also makes provisions for the establishment of a National Research Fund. This policy was, in turn, reviewed in 2012 and 2013. Tanzania also published a policy on biotechnology in December 2010. It is a member of the African Biosafety Network of Expertise (see Box 18.1).

The main body in charge of STI policy in Tanzania is the Ministry of Communication, Science and Technology and its main co-ordinating agency, the Commission for Science and Technology (COSTECH). COSTECH co-ordinates a number of research institutes engaged with industry, health care, agriculture, natural resources, energy and the environment.

Tanzania occupies the second-lowest rank for the KEI and KI among the viable national innovation systems in the SADC region. Basic R&D indicators send conflicting signals. Despite a GERD/GDP ratio of 0.38% of GDP, there were just 69 researchers (head count) per million population in 2010. One in four researchers is a woman (see Figure 19.3). The UNESCO Dar es Salaam office has been leading the reform of STI in Tanzania within the United Nations Development Assistance Programme for 2011–2015 (formerly the One UN Programme) since 2008. As part of this programme, UNESCO commissioned a series of studies, including one on biotechnology and bio-entrepreneurship (Box 20.5) and another on the participation of women in industries based on science, engineering and technology, which spawned a project to improve Maasai homes (Box 20.6).

Even though Tanzania has eight public institutions of higher education and a plethora of private institutions, fewer than half of secondary school-leavers who qualify for entry obtain a place at university. The establishment of the Nelson Mandela African Institute of Science and Technology in Arusha in 2011 should augment Tanzania's academic capacity considerably. This university has been designed as a research-intensive institution with postgraduate programmes in science, engineering and technology. Life sciences and bio-engineering are some of the initial niche areas, taking advantage of the immense biodiversity in the region. Together with its sister institution set up in Abuja (Nigeria) in 2007, it forms the vanguard of a planned pan-African network of such institutes.

Box 20.5: **Challenges facing Tanzania's bio-industry**

A report commissioned by UNESCO has identified a number of challenges for *Biotechnology and Bio-entrepreneurship in Tanzania* (2011).

It observes, for instance, that, although the first academic degree courses in biotechnology and industrial microbiology were introduced at Sokoine University of Agriculture in 2004 and at the University of Dar es Salaam in 2005, Tanzania still lacks a critical mass of researchers with skills in biotech-related fields like bioinformatics. Even when scientists have been sent abroad for critical training, poor infrastructure prevents them from putting their newly gained knowledge into practice upon their return.

Problems encountered in diagnostics and vaccination stem from the reliance upon biologicals produced elsewhere. Biosafety regulations dating from 2005 prevent confined field trials with genetically modified organisms.

Incentives are lacking for academics to collaborate with the private sector. Obtaining a patent or developing a product does not affect an academic's remuneration and researchers are evaluated solely on the basis of their academic credentials and publications.

The current lack of university–industry collaboration leaves academic research disconnected from market needs and private funding. The University of Dar es Salaam has made an effort to expose students to the business world by creating a Business Centre and setting up the Tanzania Gatsby Foundation's project to fund student research proposals of relevance to SMEs. However, both of these schemes are of limited geographical scope and uncertain sustainability.

Most research in Tanzania is largely donor-funded via bilateral agreements, with donor funds varying from 52% to 70 % of the total. Research has benefited greatly from these funds but it does mean that research topics are preselected by donors.

The conditions for export and business incubation have improved in recent years, thanks to the adoption of an export policy and a Programme for Business Environment Strengthening for Tanzania in 2009. However, no specific fiscal incentives have been envisioned to promote business in the biotechnology sector, resource limitations being given as the principal cause. Private entrepreneurs have appealed for tax regimes to support ideas developed domestically and for the provision of loans and incubation structures to allow them to compete against foreign products.

The report also observes that communication and co-ordination between the relevant ministries may also need optimizing, in order to provide the necessary resources for policy implementation. For example, lack of co-ordination between COSTECH, the Ministry of Health and Social Welfare and the Ministry of Industry, Trade and Marketing appears to be hindering potential implementation and exploitation of patent exemptions related to the agreement on Trade-related Aspects of Intellectual Property Rights.

Source: Pahlavan (2011)

ZAMBIA

Impediments to economic transformation

Zambia's economic growth has been derived mainly from the commodities boom (especially copper), fuelled by demand from China. However, growth has not resulted in job creation and poverty reduction, as Zambia has not yet managed to diversify its resource-based economy by developing manufacturing and adding value to commodities. Copper exports constitute about 80% of foreign exchange earnings but only 6% of total revenue. Although agriculture employs about 85% of the labour force, it contributes only 10% of GDP (see Figure 19.2). Productivity is low, with agriculture representing only about 5% of exports, mostly due to its weak linkages with manufacturing. The combination of poor infrastructure, an inappropriate regulatory and tax regime, limited access to finance, a low level of skills and the generally high cost of doing business are all major impediments to economic transformation in Zambia (AfDB *et al*., 2014).

The higher education sector consists of three public universities, the University of Zambia, Copperbelt University and, since 2008, Mulungushi University. There are also 32 private universities and colleges and 48 public technical institutes and colleges. Demand nevertheless far outstrips supply, as there are only enough places for one-third of qualifying school-leavers. The low remuneration of academic staff relative to other SADC countries has also resulted in an exodus of qualified academics (SARUA, 2012).

Zambia's GERD/GDP ratio is modest (0.28% in 2008) and it counts just 49 researchers per million inhabitants. When indicators for unemployment (13% in 2013), education and poverty (Table 20.1) are taken into account, Zambia's national innovation system is clearly struggling but viable.

A fund to spur research

Zambia's *National Science and Technology Policy* dates from 1996 and the Science and Technology Act from 1997. These milestones have given rise to three key science and technology institutions, the National Science and Technology Council (NSTC), National Technology Business Centre (est. 2002) and National Institute for Scientific and Industrial Research (a research body which replaced the National Council for Scientific Research dating from 1967). The NSTC provides grants through the Strategic Research Fund, Youth

Box 20.6: Simple technology brings Maasai better homes

The concept of innovation is often associated with high technology and thus perceived by many African communities as being beyond the reach of the poor. Affordable solutions exist, however, for making life more comfortable.

In 2012, the UNESCO Dar es Salaam office worked with the advocacy group Tanzanian Women in Science and the NGO Tanzanian Women Architects for Humanity to design a series of improvements to the adobe (mud) dwellings of Maasai women in the village of Ololoskwan, at the request of a group of Maasai women.

Home-building tends to fall to the womenfolk in Maasai communities. The architects taught the women a number of techniques for improving the comfort, safety and durability of their homes *(bomas)*. In order to raise the ceiling and strengthen the structure, existing poles were replaced with sturdier, longer ones. To protect the *bomas* from water leakage, the architects designed roofs with eaves and overhangs. Sloping aprons were introduced at the foot of the walls to protect them from splashing rain. Troughs made of ferro-cement were fitted round the roof overhangs to catch rainwater and channel it into drums at the base of the structure.

To ensure the mud plaster would not erode over time, the Maasai women were shown how to add bitumen and kerosene oil to the adobe mixture of clay and sand. The adobe was then blended with cow dung to produce a hard cement. This lengthened the time before the structures would need any maintenance from two to 5–10 years.

The stove in the centre of the room was relocated to a corner and surrounded on two sides by a clay brick wall, in order to help direct smoke upward. A hood or chimney channelled the smoke outside.

The windows were enlarged to let in more light and improve ventilation. Solar panels were introduced to provide lighting. The SunLite Solar Kit (*circa* US$ 50) consists of a solar panel, control-box with charger and battery and a bright LED light; the kit comes with a long cable and wiring that can be connected to most mobile phones, enabling owners to charge their own mobile phones and earn extra income from providing the service to others.

The two Maasai showhomes were completed in August 2012. Nearby villages sent emissaries, many of whom were so impressed that they offered to pay the women to build model homes for them. The women are now contemplating setting up a small construction business.

This project was funded by the United Nations Development Assistance Plan for 2011–2015, within a wider drive to give women a bigger role in harnessing STI to national development.

Source: Anthony Maduekwe, UNESCO

Innovation Fund and Joint Research Fund. It also administers the Science and Technology Development Fund instituted by the Science and Technology Act (1997). This fund encourages research that contributes to the goals of the *Fifth (*2006–2010) and *Sixth National Development Plans* and *Vision 2030 (*2006*)* for a prosperous middle-income nation by 2030, especially projects targeting a better standard of living, innovation, value addition to natural resources and the integration of locally produced technologies in the Zambian industrial sector, not to mention the purchase, maintenance or repair of equipment. For its part, the National Technology Business Centre (est. 2002) administers a Business Development Fund.

A strong commitment to agriculture

A Biosafety Act was adopted in 2007 (see map in Box 18.1). Zambia is surpassed only by Malawi within the SADC region for the level of public expenditure on agriculture: 10% of GDP in 2010. However, the country's main centre for agricultural research, the Zambian Agricultural Research Institute, 'is in a dire situation', having suffered a 30% decline in the staffing table, which counted 120 professional staff, 120 technicians and 340 support staff in 2010. The institute plays an essential role in maintaining laboratories for specialized research, while managing the country's seed bank. Very little donor funding has been forthcoming, leaving the government to shoulder 90–95% of the burden. The private non-profit Golden Valley Agricultural Research Trust[23] is trying to compensate for the staff cuts at its sister institute but it, too, is reliant on government and international donor funding – only 40% of its income comes from commercial farming and contract research (UNESCO, 2014b).

ZIMBABWE

A country emerging from a long crisis

Between 1998 and 2008, the Zimbabwean economy contracted by a cumulative 50.3%, sending GDP per capita plummeting to less than US $400. In July 2008, inflation peaked at 231 000 000%. By this time, 90% of the population was unemployed and 80% were living in poverty. Infrastructure had deteriorated, the economy had become more informal and there were severe food and foreign currency shortages. The economic crisis was accompanied by a series of political crises, including a contested election in 2008 which resulted in the formation of a government of national unity in February 2009 (UNESCO, 2014b).

The economic crisis coincided with the implementation of the Fast-track Land Reform Programme from 2000 onwards which compounded the decline in agricultural production by reducing the cropping area of traditionally large commercial crops such as wheat and maize. In parallel, FDI shrank after the imposition of Western sanctions and the suspension of IMF technical assistance due to the non-payment of arrears. Hyperinflation was only brought under control in 2009 after the adoption of a multicurrency payment system and economic recovery programme. Once stabilized, the economy grew by 6% in 2009 and FDI increased slightly; by 2012, it amounted to US$ 392 million (UNESCO, 2014b).

Zimbabwe continues to score poorly for governance indicators. In 2014, it ranked 156th (out of 175) in the Corruption Perceptions Index and 46th (out of 52) in the Ibrahim Index of African Governance in 2014 (see Table 19.1). The economy remains fragile, plagued by high external debt, degraded infrastructure and an uncertain policy environment (AfDB *et al*., 2014). The lack of co-ordination and coherence among governance structures has led to poor implementation of existing policies and the multiplication of research priorities (UNESCO, 2014b).

An uncertain policy environment

The *Second Science and Technology Policy* was launched in June 2012, after being elaborated with UNESCO assistance. It replaces the earlier policy dating from 2002 and has six main objectives:

- Strengthen capacity development in STI;
- Learn and utilize emerging technologies to accelerate development;
- Accelerate commercialization of research results;
- Search for scientific solutions to global environmental challenges;
- Mobilize resources and popularize science and technology; and
- Foster international collaboration in STI.

The *Second Science and Technology Policy* cites sectorial policies with a focus on biotechnology, ICTs, space sciences, nanotechnology, indigenous knowledge systems, technologies yet to emerge and scientific solutions to emergent environmental challenges. The policy makes provisions for establishing a National Nanotechnology Programme. There is also a *National Biotechnology Policy* which dates from 2005. Despite poor infrastructure and a lack of both human and financial resources, biotechnology research is better established in Zimbabwe than in most sub-Saharan countries, even if it tends to use primarily traditional techniques.

The *Second Science and Technology Policy* asserts the government commitment to allocating at least 1% of GDP to GERD, focusing at least 60% of university education on developing skills in science and technology and ensuring that school pupils devote at least 30% of their time to studying science subjects (UNESCO, 2014b).

23. The Agricultural Research Trust has also been active in Zimbabwe since 1981.

Following the elections of 2013, the incoming government replaced the *Medium Term Plan 2011–2015* elaborated by its predecessor with a new development plan, the *Zimbabwe Agenda for Sustainable Economic Transformation* (ZimAsset, 2013–2018). One objective of ZimAsset is to rehabilitate and upgrade national infrastructure, including the national power grid, road and railway network, water storage and sanitation, buildings and ICT-related infrastructure (UNESCO, 2014b).

In 2013, the Ministry of Science and Technology Development (dating from 2005) was disbanded and its portfolio relegated to the newly established Department of Science and Technology within the Ministry of Higher and Tertiary Education, Science and Technology Development.

The same year, the government approved four national research priorities proposed by the Research Council of Zimbabwe:

- The social sciences and humanities;
- Sustainable environmental and resource management;
- Promoting and maintaining good health; and
- The national security of Zimbabwe.

A worrying exodus of skills

Zimbabwe has a long research tradition that dates back a century. However, the economic crisis has precipitated an exodus of university students and professionals in key areas of expertise (medicine, engineering, etc.) that is of growing concern. More than 22% of Zimbabwean tertiary students are completing their degrees abroad. In 2012, there were just 200 researchers (head count)[24] employed in the public sector, one-quarter of whom were women. The government has created the Zimbabwe Human Capital Website to provide information for the diaspora on job and investment opportunities in Zimbabwe. Of note is that ZimAsset contains no specific targets for increasing the number of scientists and engineers (UNESCO, 2014b).

Despite the turbulence of recent years, Zimbabwe's education sector remains sound. In 2012, 91% of youth aged 15–24 years were literate, 53% of the population aged 25 years or more had completed secondary education and 3% of adults held a tertiary qualification. The government is planning to establish two new universities with a focus on agricultural science and technology: Marondera and Monicaland State Universities (UNESCO, 2014b).

The long-standing University of Zimbabwe is particularly active in research, producing more than 44% of Zimbabwe's scientific publications in 2013. Productivity is fairly low but the number of publications has grown since 2005 (Figure 20.6).

24. or 95 full-time equivalents

The past decade has seen an extraordinary rise in the number of copublications with foreign partners, which now represent 75–80% of all Zimbabwean publications in the Web of Science (UNESCO, 2014b).

Poor linkages with industry

Public–private linkages remain weak. With the exception of the long-standing tobacco industry and others oriented towards agriculture, there has traditionally been little collaboration between industry and academia in Zimbabwe. The current regulatory framework hampers the transfer of technology to the business sector and the development of industrial R&D, despite the commercialization of research results being one of the major goals of the *Second Science, Technology and Innovation Policy* (UNESCO, 2014b).

The government is currently analysing new legislation that would promote local cutting and polishing of diamonds to create an estimated 1 700 new jobs. It has already slashed license fees for local cutting and polishing firms. Mining accounts for 15% of GDP and generates about US$ 1.7 billion in exports annually; despite this, the government receives royalties of only US$ 200 million. Currently, the entire stock of diamonds is exported in raw form. The new legislation will require companies to pay a 15% value-added tax but they will incur a 50% discount if they decide to sell their diamonds to the Minerals Marketing Corporation of Zimbabwe (UNESCO, 2014b).

CONCLUSION

From economic integration to a regional innovation system?

To date, intra-African trade remains dismally low, at approximately 12% of total African trade,[25] in spite of the formation of numerous regional economic communities. Both prominent pan-African organizations, such as the African Union (AU) and the New Partnership for Africa's Development (NEPAD), and regional bodies such as SADC have clear visions of the criteria for integration and the rationale behind it. The development of regional STI programmes is high on the list of priorities. However, several factors are hampering economic integration, including the similar economic structure of countries – based on mineral resources and agriculture –, poor economic diversification and low levels of intraregional trade. Nevertheless, the most formidable obstacle of all to regional integration is probably the resistance of individual governments to relinquishing national sovereignty.

Some argue that the only feasible route to sustainable socio-economic development, which has eluded most African countries, is to pursue regional integration.

25. compared to about 55% in Asia and 70% in Europe

This counter-argument agitates the promise of a huge internal market and the opportunities that it would offer for the development of economies of scale and scope. Another convincing argument arises from the increasingly urgent requirement for Africa to engage in a unified manner with a world that is increasingly characterized by economic blocs and large emerging economic powers.

An important aspect of economic integration would be the transition from national innovation systems to a single regional innovation system. Along with the establishment of free trade areas in order to construct the planned common market with full mobility of goods and services, capital and people, this would require the convergence of formal institutions, including labour market legislation, environmental regulation and policies governing competition. The opening up of borders to the free movement of people and services would also enable informal cross-border pools of tacit knowledge and social capital to emerge. The ultimate goal would be the emergence of a regional innovation system on the back of the development of an increasingly diversified economic system.

The AU-NEPAD *African Action Plan* for 2010–2015 has identified a number of obstacles to the evolution of national innovation systems across the region which resonate with those identified by the *SADC Regional Indicative Strategic Development Plan* back in 2003, namely:

- SADC economies are dominated by agriculture and mining with a poorly developed manufacturing sector;
- The GERD/GDP ratio is significantly lower in most SADC countries than the 1% benchmark set by the African Union in 2003 for the African continent;
- Governments offer few incentives for private-sector investment in R&D;
- There are serious shortages of scientific and technological skills at all levels (from artisans and technicians to engineers and scientists); this shortage is exacerbated by the ongoing brain drain;
- School education in science and technology is poor, primarily due to a lack of qualified teachers and inappropriate curricula; this type of education is also heavily biased against girls and women;
- There is generally poor protection of intellectual property rights in legislation; and
- There is little co-operation in science and technology across the region.

KEY TARGETS FOR SOUTHERN AFRICA

- Raise GERD in SADC countries to at least 1% of GDP by 2015;
- Ensure that 50% of decision-making positions in the public sector in SADC countries are held by women by 2015;
- Increase trade among SADC countries to at least 35% of total SADC trade, compared to 10% in 2008;
- Increase the share of manufacturing in SADC countries to 25% of GDP by 2015;
- Achieve 100% connectivity to the regional power grid for all SADC member states by 2012;
- Raise the share of public expenditure on agriculture to 10% of GDP in all SADC countries;
- Raise the GERD/GDP ratio in Botswana from 0.26% in 2012 to over 2% by 2016;
- Raise public expenditure on R&D in Mauritius to 1% of GDP by 2025, with a further 0.5% of GDP to come from the private sector;
- Focus at least 60% of university education in Zimbabwe on developing skills in science and technology;
- Generate 100 000 PhDs in South Africa by 2030;
- Generate 100 PhDs by 2024 from Angola's new Centre of Excellence for Science Applied to Sustainability.

REFERENCES

AfDB (2013) *African Economic Outlook 2013. Special Thematic Edition: Structural Transformation and Natural Resources*. African Development Bank.

AfDB (2011) *Republic of Mozambique: Country Strategy Paper 2011–2015*. African Development Bank.

AfDB, OECD and UNDP (2014) *African Economic Outlook*. Country notes. African Development Bank, Organisation for Economic Co-operation and Development and United Nations Development Programme.

Cassiolato, J. E. and H. Lastres (2008) *Discussing innovation and development: Converging points between the Latin American school and the Innovation Systems perspective?* Working Paper Series (08-02). Global Network for Economics of Learning, Innovation and Competence Building System (Globelics).

Government of Lesotho and UNDP (2014) *Lesotho Millennium Development Goals Status Report – 2013*.

IERI (2014) *Revisiting some of the Theoretical and Policy Aspects of Innovation and Development*. IERI Working Paper 2014-1. Institute for Economic Research on Innovation: Pretoria.

IFC (2013) *Madagascar Country Profile 2013*. International Finance Corporation. World Bank: Washington, D.C.

IMF (2014) *World Economic Outlook*, World Economic and Financial Surveys. International Monetary Fund.

Lan, G; Blom A; Kamalski J; Lau, G; Baas J and M. Adil (2014) *A Decade of Development in Sub-Saharan African Science, Technology, Engineering and Mathematics Research*. World Bank: Washington DC.

Morna, C. L.; Dube, S.; Makamure, L. and K. V. Robinson (2014) *SADC Gender Protocol Baseline Barometer*. Allied Print: Johannesburg.

OECD (2007) *OECD Reviews of Innovation Policy: South Africa*. Organisation for Economic Co-operation and Development.

Pahlavan, G. (2011) *Biotechnology and Bioentrepreneurship in Tanzania*. UNESCO and Ifakara Health Institute: Dar es Salaam. See: http://tinyurl.com/9kgg2br.

Ravetz, J. (2013) *Mauritius National Research Foresight Exercise: Prospectus and Summary Report*. Manchester Institute of Innovation Research and Centre for Urban and Regional Ecology: University of Manchester (UK).

Republic of Botswana (2011) *National Policy on Research, Science, Technology and Innovation, 2011*. Ministry of Infrastructure, Science and Technology: Gaborone.

Republic of Mozambique (2001) *Action Plan for the Reduction of Absolute Poverty: 2001–2005*.

Republic of South Africa (2012) *Report of the Ministerial Review Committee on the National System of Innovation*. South African Department of Science and Technology: Pretoria.

SARUA (2012) *A Profile of Higher Education in Southern Africa – Volume 2: National Perspectives*. Southern African Regional Universities Association: Johannesburg.

SARUA (2009) *Towards a Common Future: Higher Education in the SADC Region: Regional Country Profiles – Swaziland*. Southern African Regional Universities Association.

UIS (2012) *New Patterns in Mobility in the Southern African Development Community*. Information Bulletin no. 7. UNESCO Institute for Statistics: Montreal.

UNESCO (2014a) *Mapping Research and Innovation in the Republic of Malawi*. G. A. Lemarchand and S. Schneegans, eds. GO→SPIN Country Profiles in Science, Technology and Innovation Policy, 3. UNESCO: Paris.

UNESCO (2014b) *Mapping Research and Innovation in the Republic of Zimbabwe*. G. A. Lemarchand and S. Schneegans, eds. GO→SPIN Country Profiles in Science, Technology and Innovation Policy, 2. UNESCO: Paris.

UNESCO (2013) *Mapping Research and Innovation in the Republic of Botswana*. G. A. Lemarchand and S. Schneegans, eds. GO→SPIN Country Profiles in Science, Technology and Innovation Policy, 1. UNESCO: Paris.

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Without adequate resources, it is unlikely that [research and education] policies will bring about effective change.

Dilupa Nakandala and **Ammar Malik**

Mahfuza answers farmer Nojrul Islam's question about using fertilizer on his crops by showing him a video on her laptop offering advice. In rural Bangladesh, the Info Ladies service brings internet services to men and women who need information but lack the means to access the web.
Photo © GMB Akash/Panos Pictures

21 · South Asia

Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka

Dilupa Nakandala and Ammar Malik

INTRODUCTION

Healthy economic growth

To the outsider, the seven economies of South Asia covered in the present chapter may appear to possess similar characteristics and dynamics. In reality, however, they are quite diverse. Afghanistan, Bangladesh and Nepal are low-income economies, Bhutan, Pakistan and Sri Lanka are lower middle-income economies and the Maldives is an upper middle-income economy.

According to the 2013 UNDP human development index, only Sri Lanka has achieved a high level of human development. Bangladesh, Bhutan and Maldives enjoy medium levels and the remainder are still at a stage of low development. Between 2008 and 2013, human development progressed in Bangladesh, the Maldives, Nepal and Sri Lanka but receded slightly in Pakistan, mainly due to the unstable security situation in parts of the country.

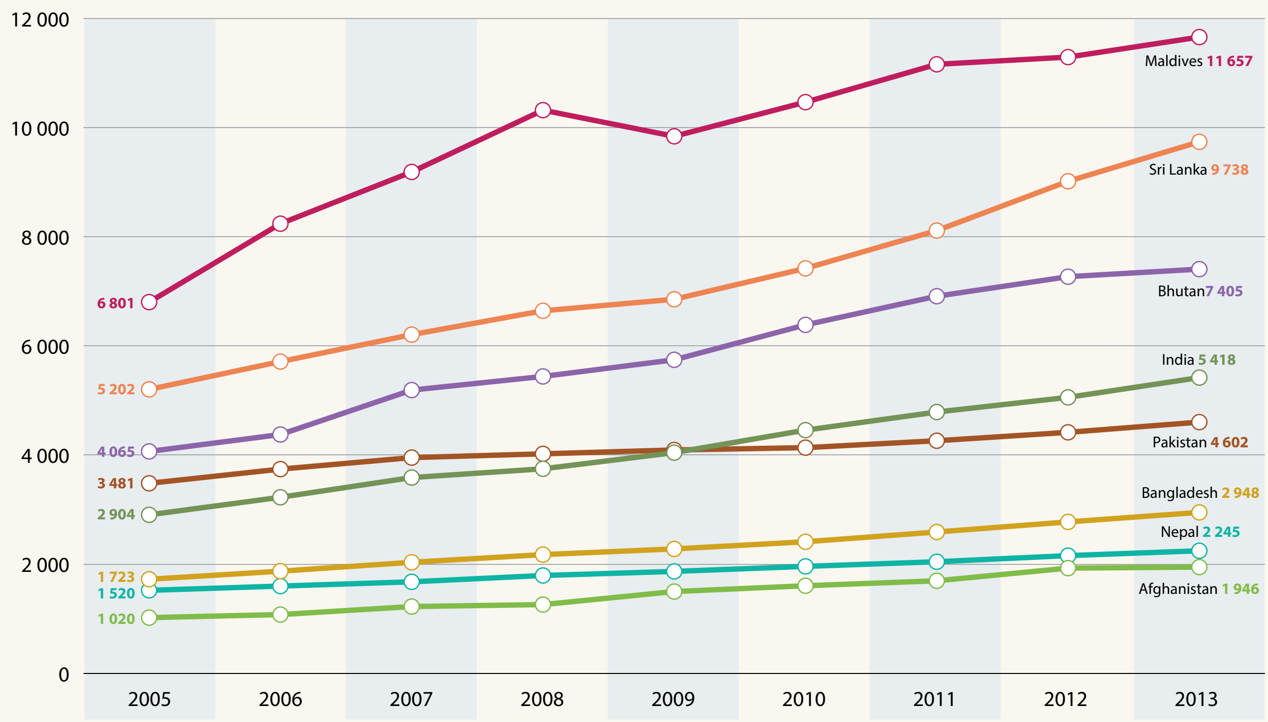
Three out of four South Asians are Indian. This single country accounts for 80% of the region's GDP of US$ 2 368 trillion. As India is the object of a separate chapter (see Chapter 22), the present essay will focus on the other seven members of the South Asian Association for Regional Cooperation (SAARC). Excluding India, GDP grew by a healthy 6.5% in the region in 2013. Sri Lanka reported the fastest progression (7.25%) and the Maldives (3.71%) and Nepal (3.78%) the slowest. GDP per capita, on the other hand, has risen fastest in the Maldives, followed by Sri Lanka (Figure 21.1).

FDI insufficient but trade growing

The rise in export and import trade volumes in recent years confirms the growing integration of South Asia in the global economy. Bangladesh has even managed to outperform its neighbours, with its exports progressing from 16% to 19.5% of GDP between 2010 and 2013. Moreover, Bangladesh managed to maintain a stable level of exports and foreign direct investment (FDI) at the height of the global financial crisis in 2008–2009. Amjad and Din (2010) have identified the insufficient diversification of exports and low domestic consumption as shock amplifiers during the global crisis; for them, sound economic management helped maintain macro-economic stability in Bangladesh, despite global food and fuel price hikes over this period.

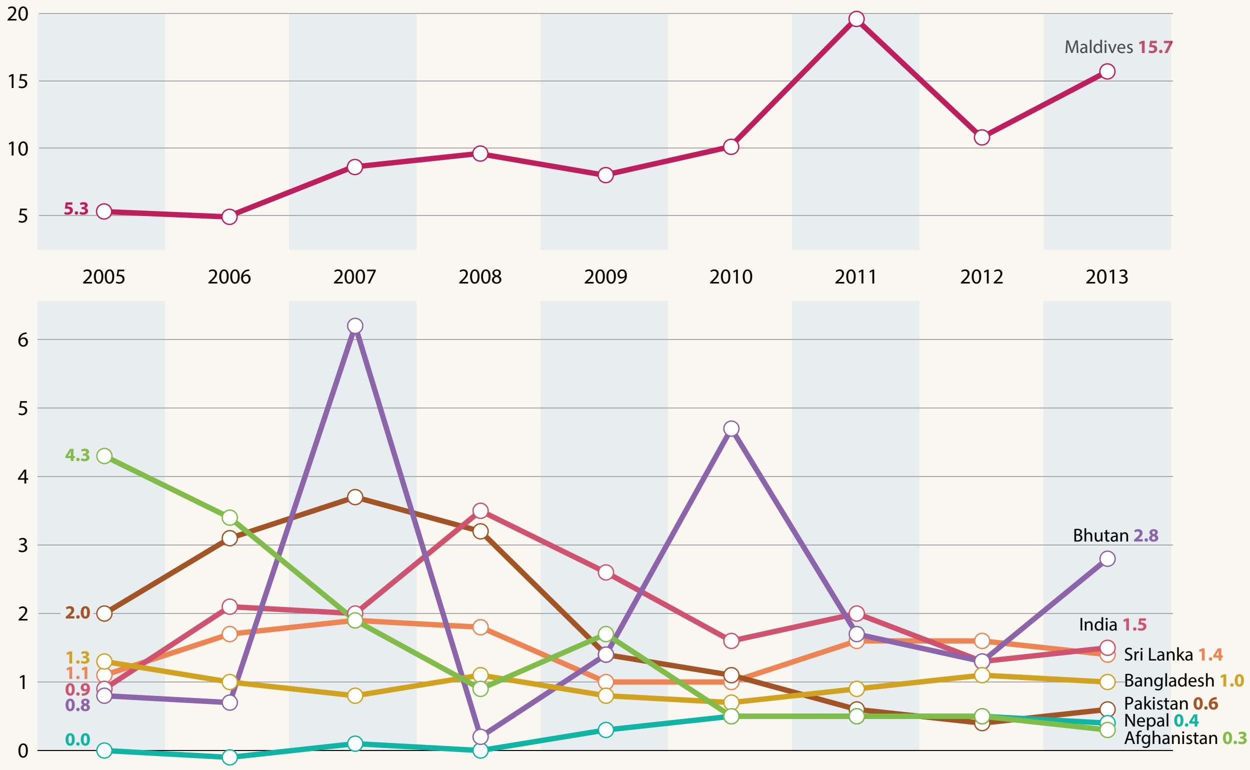
Figure 21.1: **GDP per capita in South Asia, 2005–2013**

In current PPP$



Source: World Bank's World Development Indicators, April 2015

Figure 21.2: **FDI inflows to South Asia as a share of GDP, 2005–2013 (%)**



Source: World Bank's World Development Indicators, accessed April 2015

Afghanistan and Pakistan, in particular, were less fortunate. The Maldives, on the other hand, sailed through the global financial crisis to become an increasingly attractive destination for FDI (Figure 21.2). It is the exception which confirms the rule. With inflows not exceeding 5% of GDP over the past decade in all but Bhutan and the Maldives, South Asia is hardly a pole of attraction for FDI. The total amount of announced greenfield investments (see the glossary, p. 738) in South Asia dropped to US$ 24 million in 2013, down from US$ 87 million in 2008. India hosted 72% of the region's greenfield FDI in 2013.

Political instability has long been a barrier to development in South Asia. Although Sri Lanka emerged from three decades of civil war in 2009 and the Nepalese civil war has been over since 2006, the rehabilitation and reconstruction of these nations will be long-term enterprises. There was a smooth political transition in Sri Lanka in January 2015, when Maithripala Sirisena was elected president in an election called two years ahead of schedule by the incumbent president Mahinda Rajapaksa. Two months later, in the Maldives, former president Mohamed Nasheed was jailed for 13 years following a trial which the United Nations' High Commissioner for Human Rights described as 'a rushed process'. In Afghanistan, civil society has developed considerably since 2001 but the protracted negotiations to form a government after the presidential election of April 2014 reflect the fragility of the ongoing transition to democracy; this process will need to be consolidated by the time the forces of the North Atlantic Treaty Organization (NATO) withdraw from Afghanistan in 2016.

Barriers remain to intra-regional trade

South Asia remains one of the world's least economically integrated regions, with intraregional trade accounting for merely 5% of total trade (World Bank, 2014). It has been nine years since the South Asian Free Trade Area (SAFTA) agreement entered into force on 1 January 2006, committing the eight[1] signatories (with India) to reducing customs duties on all traded goods to zero by 2016.

Nine years on, regional trade and investment remain limited, despite countries having embraced global trade liberalization. This is due to a host of logistical and institutional barriers, such as visa restrictions and the lack of regional chambers of commerce. Even though various studies have argued that greater trade would produce net gains in social welfare, businesses are unable to take advantage of potential synergies, owing to non-tariff barriers such as cumbersome processes for obtaining customs clearance (Gopalan *et al.*, 2013).

1. Afghanistan ratified the agreement in May 2011.

Since its inception in 1985, SAARC has failed to emulate the success of the neighbouring Association of Southeast Asian Nations in fostering regional integration in trade and other areas, including in science, technology and innovation (STI). Tangible results largely elude SAARC, beyond a series of agreements and regular summits involving heads of government (Saez, 2012). Several explanations have been put forward but the most prominent of these remains the persistently tense relations between India and Pakistan, traditional security concerns having been fuelled by the threat of terrorism in recent years. At the November 2014 SAARC summit, Indian Prime Minister Narendra Modi nevertheless invited SAARC members to offer Indian companies greater investment opportunities in their countries, assuring them of greater access to India's large consumer market in return. After a tragic earthquake struck Nepal on 25 April 2015, killing more than 8 000 and flattening or damaging more than 450 000 buildings, all SAARC members were quick to show their solidarity through the provision of emergency aid.

In the past decade, India has assumed responsibility for hosting two regional bodies, the South Asian University (Box 21.1) and the Regional Biotechnology Centre for training and research (see p. 612). These success stories illustrate the potential of STI for fostering regional integration. There are also instances of bilateral co-operation in STI. For instance, an Indo-Sri Lankan Joint Committee on Science and Technology was set up in 2011, along with an Indo-Sri Lankan Joint Research Programme. The first call for proposals in 2012 covered research topics in food science and technology; applications of nuclear technology; oceanography and Earth science; biotechnology and pharmaceuticals; materials science; medical research, including traditional medical systems; and spatial data infrastructure and space science. Two bilateral workshops were held in 2013 to discuss potential research collaboration on transdermal drug delivery systems and clinical, diagnostic, chemotherapeutic and entomological aspects of Leishmaniasis, a disease prevalent in both India and Sri Lanka that is transmitted to humans through the bite of infected sandflies.

Box 21.1: **The South Asian University: shared investment, shared benefits**

The South Asian University opened its doors to students in August 2010. It plans to become a centre of excellence with world-class facilities and staff. It currently offers seven PhD and master's programmes in applied mathematics, biotechnology, computer science, development economics, international relations, law and sociology.

Students come predominantly from the eight SAARC countries and enjoy heavily subsidized tuition fees. Some students from non-SAARC countries may also be admitted on a full cost-recovery basis. Admission is governed by a quota system, whereby each member country is entitled to a specific number of seats in each programme of study. Every year, the university conducts a SAARC-wide entrance test in all the major cities of South Asia. PhD aspirants also have to present their thesis proposal and undergo a personal interview. In 2013, the university received 4 133 applications for its programmes from all eight South Asian countries, double the number in 2012. There were 500 applications alone for the 10 places on offer for the doctoral programme in biotechnology.

The university is being temporarily hosted by the Akbar Bhawan Campus in Chanakyapuri, New Delhi, before moving to its 100-acre campus in Maidan Garhi in South Delhi by 2017. The task of designing the campus has been entrusted to a Nepalese firm of architects through a competitive bidding process.

The capital cost of establishing the university is being covered by the Indian government, whereas all eight SAARC member countries share the operational costs in mutually agreed proportions.

The university focuses on research and postgraduate level programmes. It will ultimately have 12 postgraduate faculties, as well as a Faculty of Undergraduate Studies. At full strength, the university will count 7 000 students and 700 teachers. There are also plans to establish an Institute of South Asian Studies on campus.

Degrees and certificates awarded by the university are recognized by India's University Grants Commission and by other SAARC countries.

Attractive salary packages and benefits have been designed to attract the best teachers. Although they tend to come from the eight SAARC countries, up to 20% may come from other countries.

The idea of a South Asian University was mooted by the Prime Minister of India at the 13th SAARC Summit in Dhaka in 2005. Prof. Gowher Rizvi, a well-known historian from Bangladesh, was then entrusted with the task of preparing the concept paper, in consultation with SAARC countries. An interministerial Agreement for the Establishment of the South Asian University clinched the deal on 4 April 2007 during the following SAARC Summit in New Delhi.

Source: www.sau.ac.in

Chapter 21

TRENDS IN EDUCATION

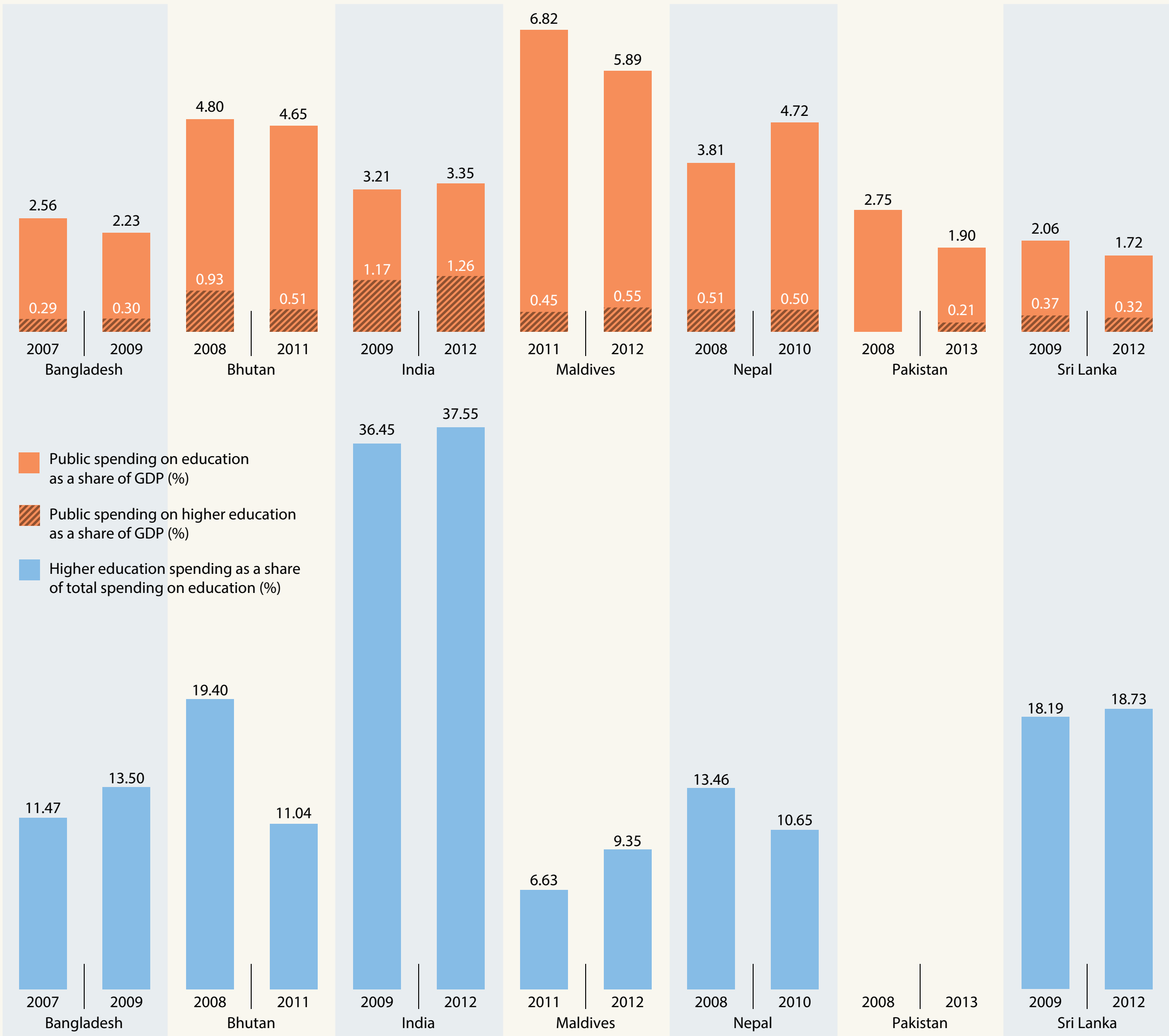
Underfunded reforms of higher education

Over the past decade, South Asian countries have embarked on an energetic drive to achieve the Millennium Development Goal (MDG) of universal primary education by 2015. Despite having rapidly achieved this target, the Maldives has consistently devoted between 5% and 7% of GDP to education over this period, more than any of its neighbours (Figure 21.3).

In all countries, higher education has had to take a back seat during this drive; the most recent data available reveal that spending on higher education amounts to just 0.3–0.6% of GDP, compared to 1.3% of GDP in India in 2012. Now that countries are on the verge of achieving universal primary education, there are growing calls for them to spend more on higher education, particularly since modernization and diversification of the economy are at the heart of their current development strategies. However, in all but Nepal, spending on education has actually been curtailed in recent years and, even in Nepal, the share allocated to higher education has stagnated (Figure 21.3).

Afghanistan is pursuing an ambitious reform of its higher education system that is yielding some impressive results, despite dependence on uncertain donor funding. Between 2010 and 2015, student enrolment doubled, for instance, as

Figure 21.3: **Public expenditure on education in South Asia, 2008 and 2013 or closest years**



Note: Data are unavailable for Afghanistan.

Source: UNESCO Institute for Statistics, April 2015; for Pakistan in 2013: Ministry of Finance (2013) *Federal Budget 2014–2015: Budget in Brief.* See: http://finance.gov.pk/budget/Budget_in_Brief_2014_15.pdf did the number of faculty members in public universities. The government adopted a gender strategy in 2013 to raise the ratio of women among students and faculty (see p. 579).

Available data for Bangladesh on tertiary enrolment show a steep rise in PhD students in engineering between 2009 and 2011 (from 178 to 521), despite a modest government investment. In Sri Lanka, the number of PhD students has climbed equally rapidly in engineering but also in science and agriculture. There is no breakdown by field of study for Pakistan but the number of PhD students also shows rapid growth (Tables 21.1 and 21.2). Pakistan and Sri Lanka now have the same share of university students enrolled in PhD programmes (1.3%) as Iran (see Figure 27.5).

ICT policies but infrastructure needs to catch up

In recent years, South Asian governments have developed policies and programmes to foster the development and use of information and communication technologies (ICTs). For instance, the Digital Bangladesh programme is central to realizing the country's vision of becoming a middle-income economy by 2021 (see p. 581). The World Bank and others are partnering with governments to accelerate the movement. Examples are the Youth Solutions! Competition for budding entrepreneurs (Box 21.2) and Bhutan's first information technology (IT) park (see p. 584).

Nowhere is this drive more visible than in education. In 2013, Bangladesh and Nepal published national plans to mainstream ICTs in education. Sri Lanka has adopted a similar plan and Bhutan is currently developing its own but work still needs to be done in the Maldives to develop a policy on ICTs in education (UIS, 2014b). The realities of a patchy, unreliable electricity supply are often fundamental obstacles to the diffusion of ICTs in rural and remote areas. In Pakistan, just 31% of rural primary schools have a reliable electricity supply, compared to 53% in urban centres, and power surges and brownouts are common in both. In Nepal, only 6% of primary schools and 24% of secondary schools had electricity in 2012 (UIS, 2014b). Another factor is the poor provision of telecommunication services through a fixed telephone line, cable connection and mobile phone technology, making it difficult to connect school computer systems with the wider network. With the exception of the Maldives, these critical pieces of ICT infrastructure are not universally available in the region. In Sri Lanka, for instance, only 32% of secondary schools have telephones.

As shown in Figure 21.4, the number of mobile phone subscribers is much higher in South Asia than the number of internet users. Mobile phone technology is increasingly being used by teachers in developing economies for both educational and administrative purposes (Valk *et al.*, 2010).

Table 21.1: **Tertiary enrolment in Bangladesh, Pakistan and Sri Lanka, 2009 and 2012 or closest years**

	Total	Post-secondary diploma	Bachelor's and master's degrees	PhD
Bangladesh (2009)	1 582 175	124 737	1 450 701	6 737
Bangladesh (2012)	2 008 337	164 588	1 836 659	7 090
Pakistan (2009)	1 226 004	62 227	1 148 251	15 526
Pakistan (2012)	1 816 949	92 221	1 701 726	23 002
Sri Lanka (2010)	261 647	12 551	246 352	2 744
Sri Lanka (2012)	271 389	23 046	244 621	3 722

Source: UNESCO Institute for Statistics, April 2015

Table 21.2: **University enrolment in Bangladesh and Sri Lanka by field of study, 2010 and 2012 or closest years**

	Science		Engineering		Agriculture		Health	
	Bachelor's and master's degrees	PhD	Bachelor's and master's degrees	PhD	Bachelor's and master's degrees	PhD	Bachelor's and master's degrees	PhD
Bangladesh (2009)	223 817	766	37 179	178	14 134	435	23 745	1 618
Bangladesh (2012)	267 884	766	62 359	521	21 074	445	28 106	1 618
Sri Lanka (2010)	24 396	250	8 989	16	4 407	56	8 261	1 891
Sri Lanka (2012)	28 688	455	14 179	147	3 259	683	8 638	1 891

Source: UNESCO Institute for Statistics, April 2015

Box 21.2: South Asia Regional Youth Grant competitions

A competition launched in 2013 in Bangladesh, the Maldives, Nepal and Sri Lanka offers young people from each country the opportunity to win a grant of US$ 10 000–20 000 to implement an innovative project of one year's duration in the field of IT.

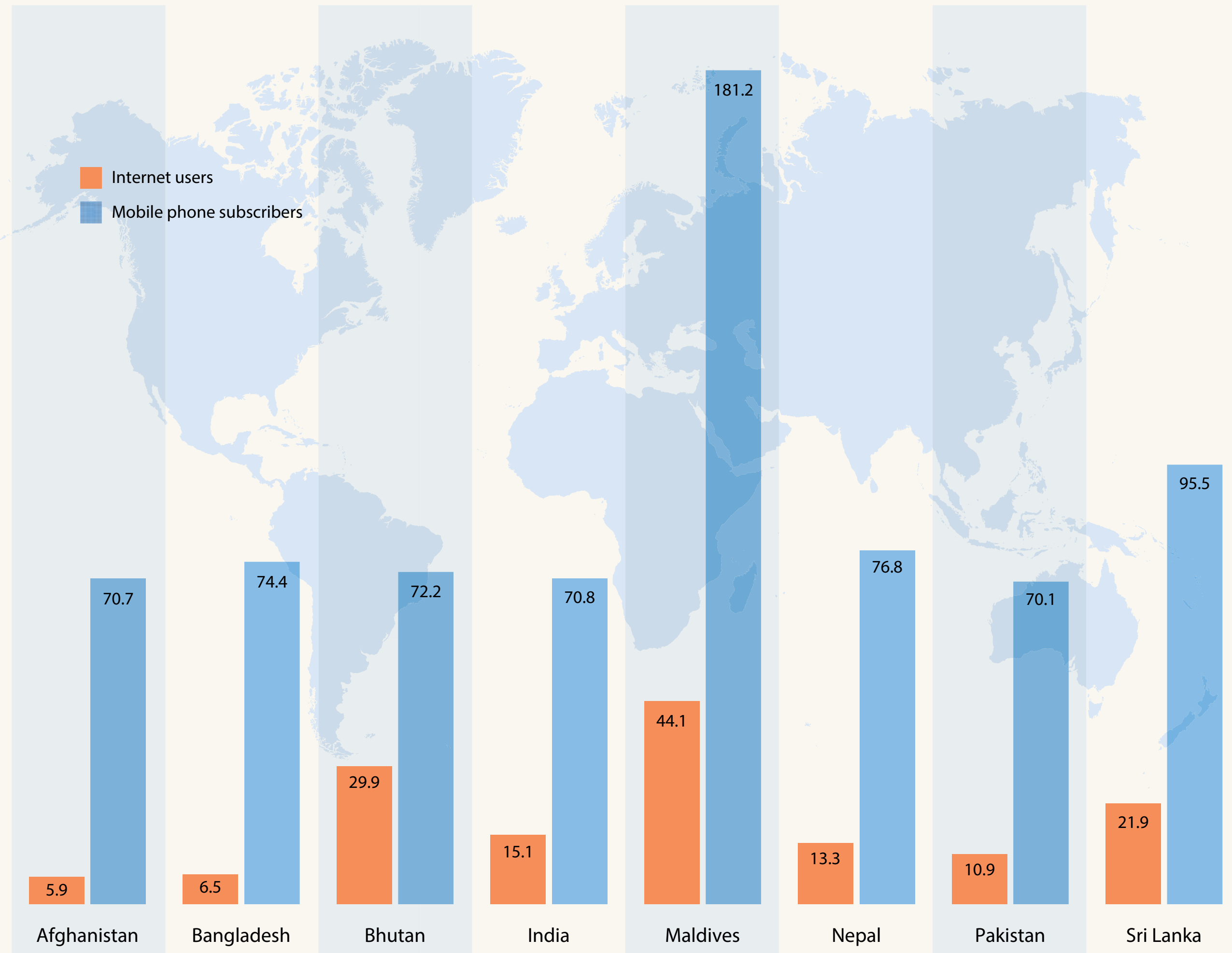
The aim is to identify innovative ideas that are ripe for the picking and allow their young creators to develop these. The competition targets reach rural youth-led social enterprises. Youth-led organizations and non-governmental organizations with two years of operation are eligible to apply, each proposal needing to have a strong focus on sustainability. The ultimate goal is to augment and diversify employment opportunities for the young.

The theme of the first grant competition was Youth Solutions! Technology for Skills and Employment (2013) and that of the second Coding Your Way to Opportunity (2014).

The scheme is the fruit of a partnership formed in March 2013 by the World Bank, Microsoft Corporation and Sarvodaya Fusion of Sri Lanka, the latter being the implementing partner. Microsoft and the World Bank, meanwhile, shortlist the innovative proposals with the support of an external evaluation panel, based on criteria that include the use of ICTs as a tool; skills development; the provision of employment opportunities; novelty; sustainability; the participatory nature; and the measurability of the outcome.

Source: World Bank

Figure 21.4: **Internet users and mobile phone subscribers per 100 inhabitants in South Asia, 2013**



Source: International Telecommunications Union

TRENDS IN R&D

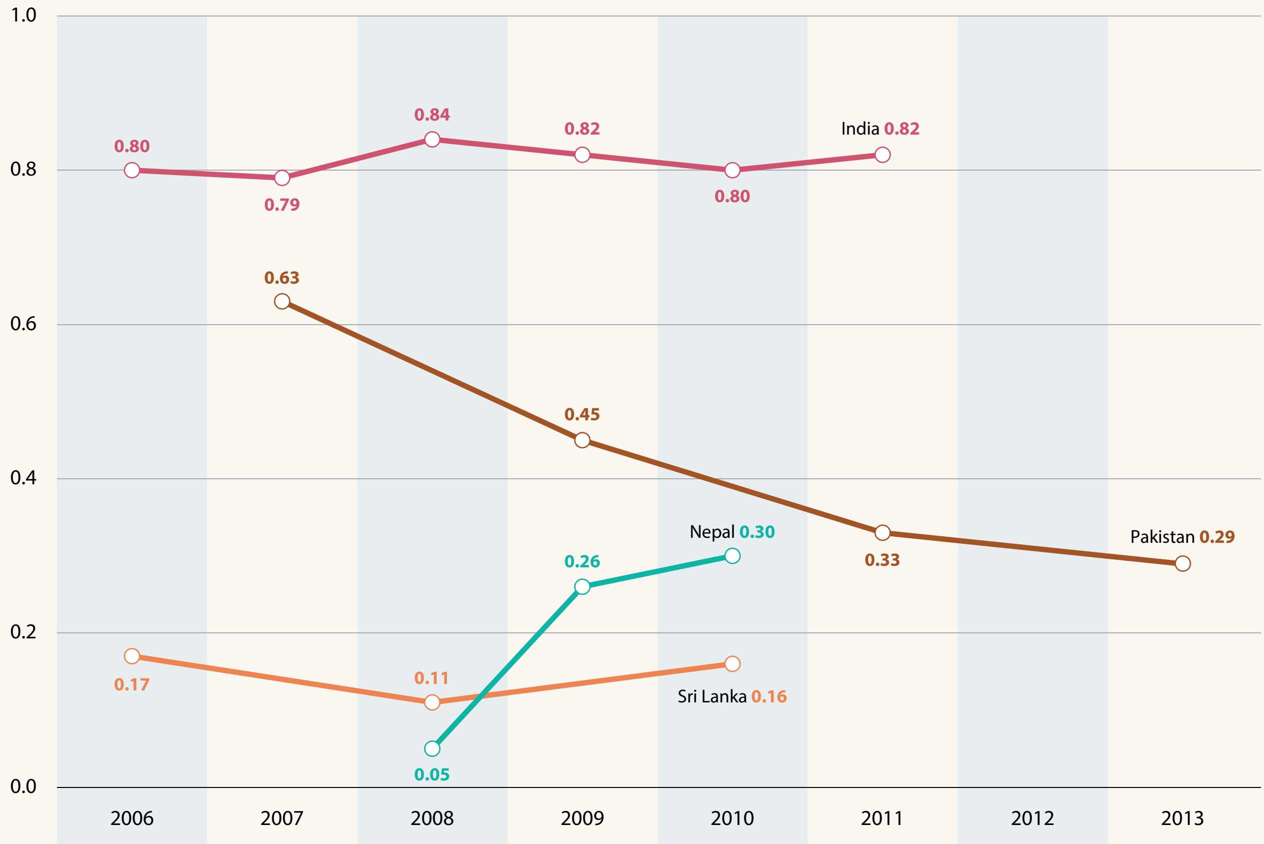
A modest R&D effort

By international standards, countries in South Asia spend modest amounts on research and development (R&D). Gross domestic expenditure on R&D (GERD) even dropped in Pakistan between 2007 and 2013 from 0.63% to 0.29% of GDP, although the government did not survey the business enterprise sector (Figure 21.5); this trend has been accompanied by an attempt in Pakistan to decentralize higher education and research spending, devolving it to the provincial level. In Sri Lanka, investment remains stable but low, at 0.16% of GDP in 2010, less than the R&D intensity of Nepal (0.30%), which has improved markedly since 2008, and far below that of India (0.82%). This lack of investment correlates with low researcher intensity and limited integration in global research networks.

As shown in Figure 21.6, the majority of countries in the region lie within a narrow range in terms of their ranking for private-sector expenditure on R&D in the World Economic Forum's Global Competitiveness Index, at between 2.28 and 3.34 in 2014, with Sri Lanka recording the best performance. Since 2010, only Nepal has shown a marginal improvement in private-sector spending on R&D. With the exception of Bangladesh and Nepal, South Asia's private sector is more implicated in R&D than in sub-Saharan Africa (average of 2.66) but less so than in emerging and developing countries, in general (3.06 on average), the notable exception being Sri Lanka. Above all, the countries of the Organisation for Economic Co-operation and Development (OECD) are streets ahead of South Asia, with an average score of 4.06, reflecting the higher level of market development in industrialized economies.

Overall, R&D spending in South Asia has not kept pace with economic growth over the past five years. The fact that both the public and private sectors exhibit similar trends is indicative of the broader lack of capacity and failure to prioritize research. This is also attributable to the relatively low levels of disposable income and commercial market development, as well as the limited margin for manoeuvre in government budgets when it comes to allocating funds to R&D.

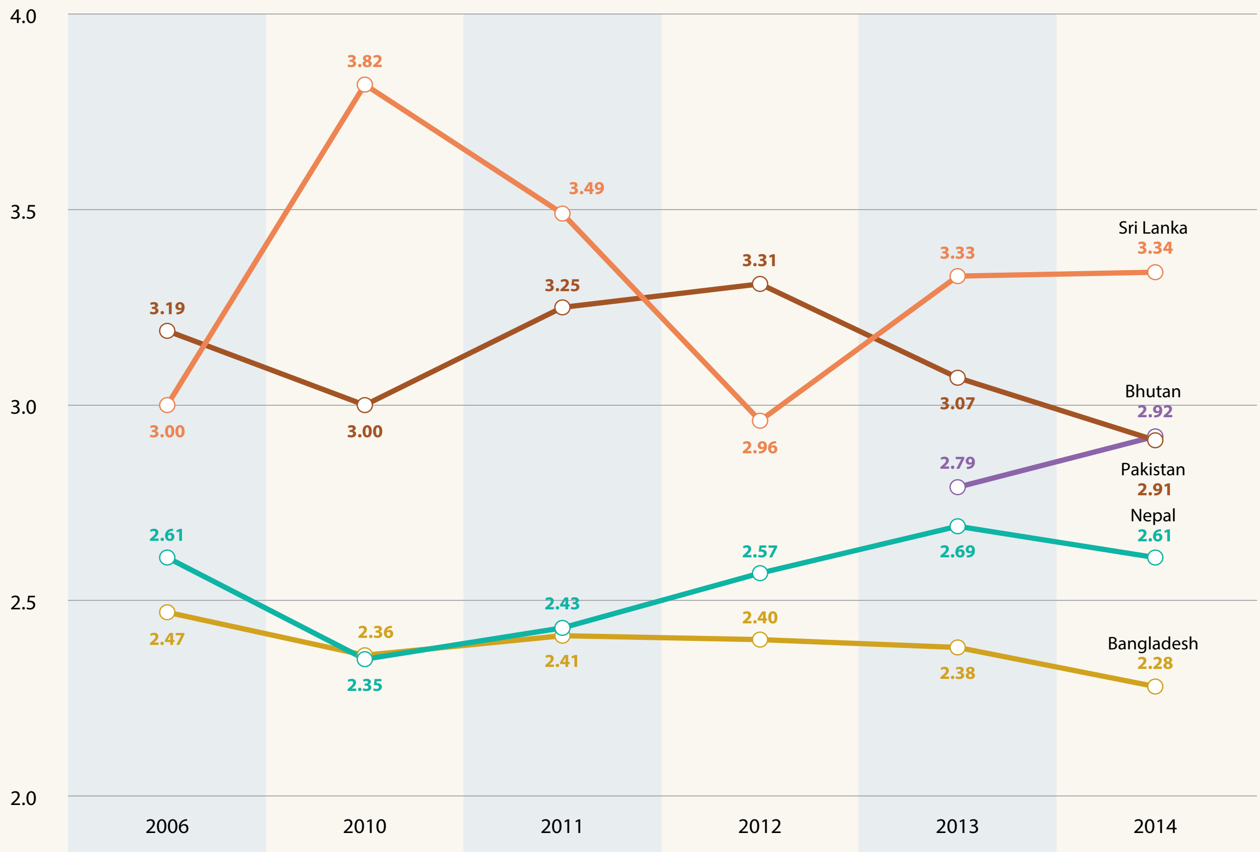
Figure 21.5: **GERD/GDP ratio in South Asia, 2006–2013**



Note: Data are unavailable for Bhutan, Bangladesh and the Maldives. The data for Nepal are partial and relate to Government R&D budget instead of R&D expenditure; those for Pakistan exclude the business enterprise sector.

Source: UNESCO Institute for Statistics, June 2015

Figure 21.6: **South Asian ranking for private-sector expenditure on R&D, 2010–2014**



Source: World Economic Forum Global Competitiveness Index, accessed December 2014

Nepal catching up to Sri Lanka for researcher density

With recent data on researchers being available only for Nepal, Pakistan and Sri Lanka, it would be hazardous to draw any conclusions for the region as a whole. However, the available data do reveal some interesting trends. Nepal is catching up to Sri Lanka in terms of researcher density but the share of women in the Nepalese research pool is low and, in 2010, was almost half that in 2002 (Figure 21.7). Sri Lanka has the greatest share of women researchers but their participation rate is lower than before. Pakistan has the greatest researcher density of the three but also the lowest density of technicians; moreover, neither indicator has progressed much since 2007.

R&D output up, despite low investment

In terms of patent applications, all countries appear to have made progress in the past five years (Table 21.3). India continues to dominate, thanks in part to the dynamism of foreign multinationals specializing in ICTs (see Chapter 22), but Pakistan and Sri Lanka have also made confident strides. Interestingly, statistics from the World Intellectual Property Organization (WIPO) for 2013 reveal that more non-resident Bangladeshis, Indians and Pakistanis are filing patent applications than before. This suggests the presence of strong diaspora communities in developed countries and/or of foreign multinationals in these countries.

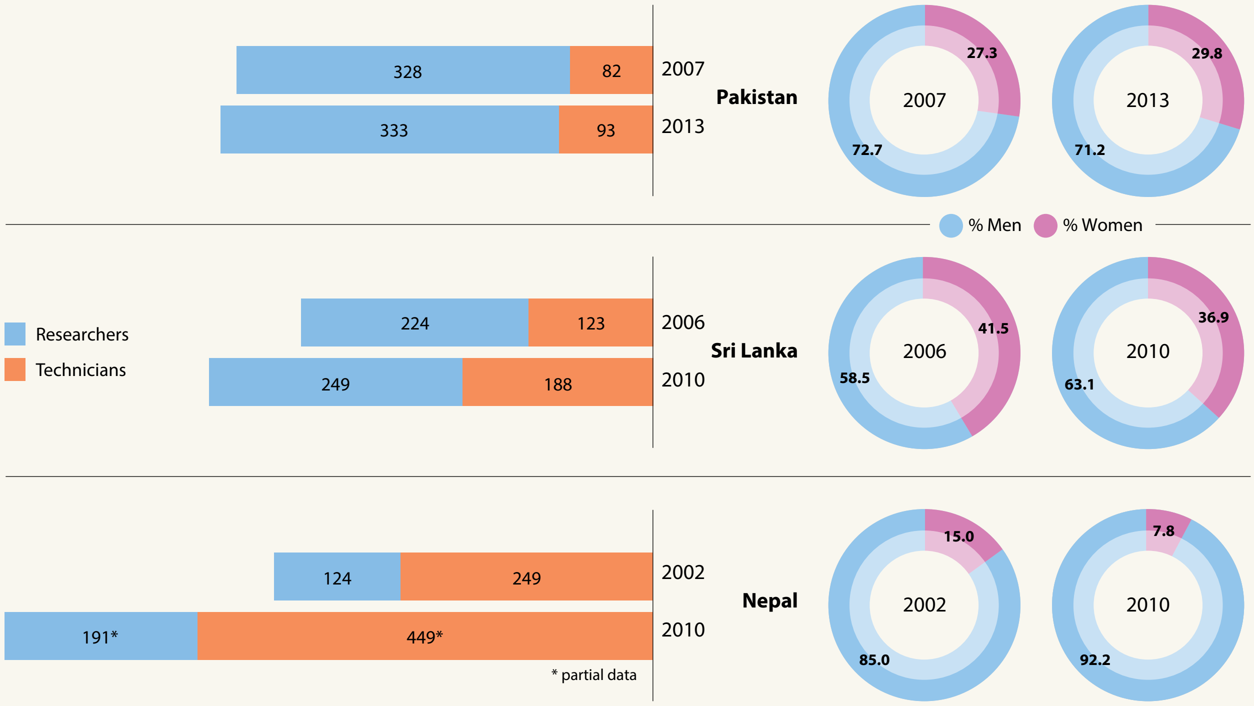
High-tech exports remain insignificant, with only India, Nepal, Pakistan and Sri Lanka reporting measureable figures: 8.1%, 0.3%, 1.9% and 1.0% respectively of their manufactured exports in 2013. However, in recent years, communications- and computer-related exports, including international telecommunications and computer data services, have dominated service exports by Afghanistan, Bangladesh and Pakistan; as for Nepal, it has shown impressive growth in this area of 36% in 2009 and 58% in 2012 as a share of service exports. Whereas Afghanistan and Nepal trade mostly with their South Asian neighbours, the other countries profiled in the present chapter limit their level of imports and exports within the region to about 25% of the total. This is essentially due to the narrow range of exports, weak consumer purchasing power within the region and insufficient regional efforts to foster the innovation needed to meet the unserved demand.

The number of scientific papers from South Asia (including India) registered in the Web of Science rose by 41.8% between 2009 and 2014 (Figure 21.8). The most spectacular progress was observed in Pakistan (87.5%), Bangladesh (58.2%) and Nepal (54.2%). In comparison, Indian publications rose by 37.9% over the same period.

Despite the stagnation in spending on higher education in Pakistan since 2008 (as a share of GDP), the momentum generated by reforms during the first decade of the century has not slowed. Meanwhile, in Nepal, the rapid increase in R&D spending between 2008 and 2010 appears to be reflected in the rise in research output, which accelerated after 2009.

Despite this progress, South Asia's research output remains modest relative to other parts of the world, be it in terms of international patents or publications in peer-reviewed journals. This lower scale of research activity is directly attributable to the lack of measureable R&D input, both from the public and private sectors. The region's academic capacity for teaching and research is also among the lowest in the world.

Figure 21.7: **Researchers (HC) and technicians in South Asia per million inhabitants and by gender, 2007 and 2013 or closest years**



Note: Data for Pakistan exclude the business enterprise sector.

Source: UNESCO Institute for Statistics, June 2015

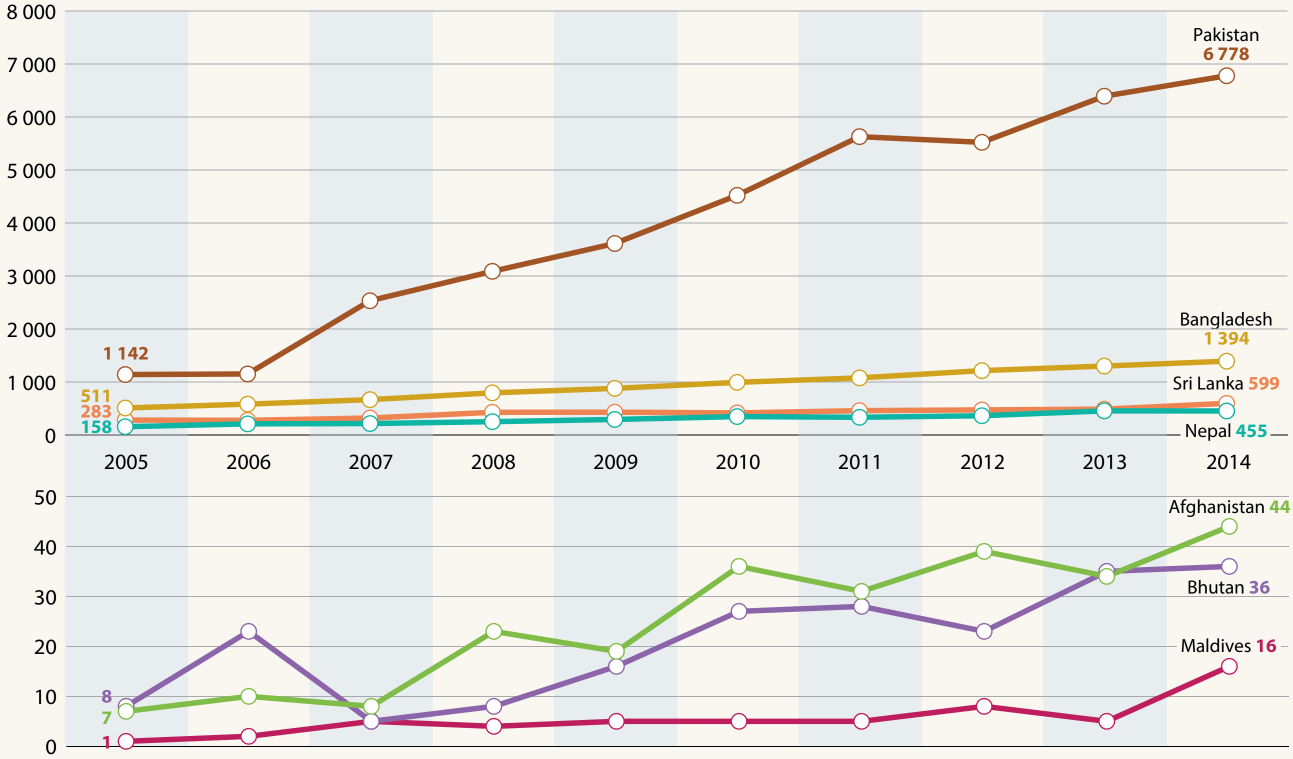
Table 21.3: **Patent applications in South Asia, 2008 and 2013**

	2008			2013		
	Total resident	Resident applications per million inhabitants	Total non-resident	Total resident	Resident applications per million inhabitants	Total non-resident
Bangladesh	29	0.19	270	60	0.39	243
Bhutan	0	0	0	3	3.00	1
India	5 314	4.53	23 626	10 669	8.62	32 362
Nepal	3	0.12	5	18	0.67	12
Pakistan	91	0.55	1 647	151	0.84	783
Sri Lanka	201	10.0	264	328	16.4	188

Source: WIPO Statistics Database, accessed April 2015

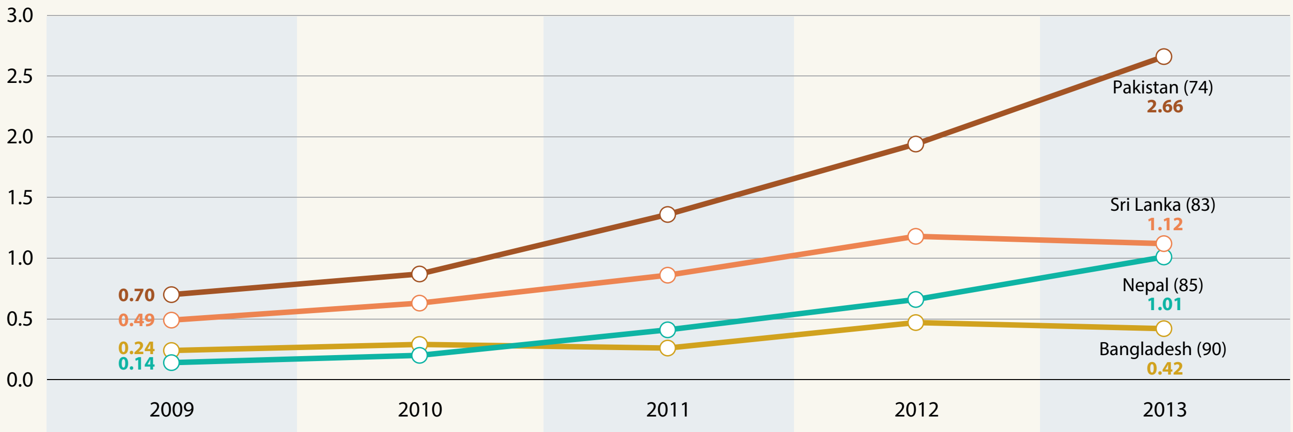
Figure 21.8: **Scientific publication trends in South Asia, 2005–2014**

Strong growth in Bangladesh, Nepal and Pakistan since 2009



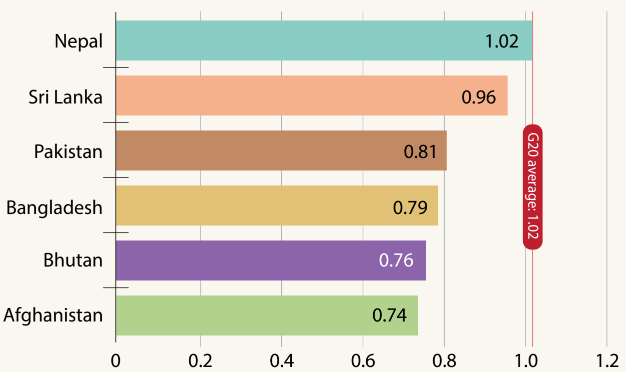
Pakistan produces the most articles related to nanotechnology per million inhabitants

Countries' world rank is shown between brackets

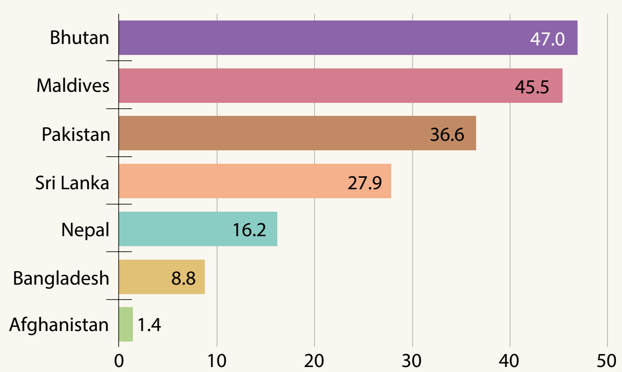


Among high-population countries, Pakistan has the greatest publication intensity

Average citation rate, 2008–2012

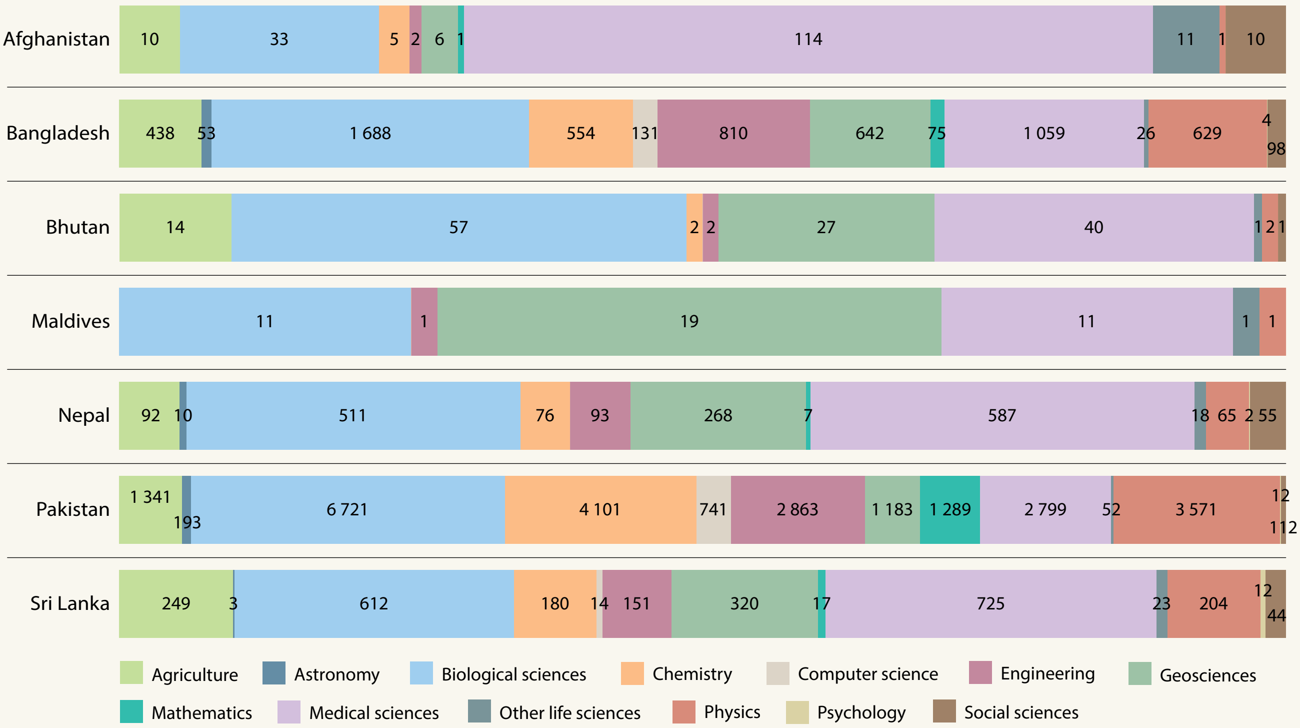


Publications per million inhabitants, 2014



Life sciences dominate in South Asia, Pakistan also specializes in chemistry

Cumulative totals by field, 2008–2014



Note: Unclassified articles are excluded from the totals.

Fellow Asians figure among South Asians' main foreign partners

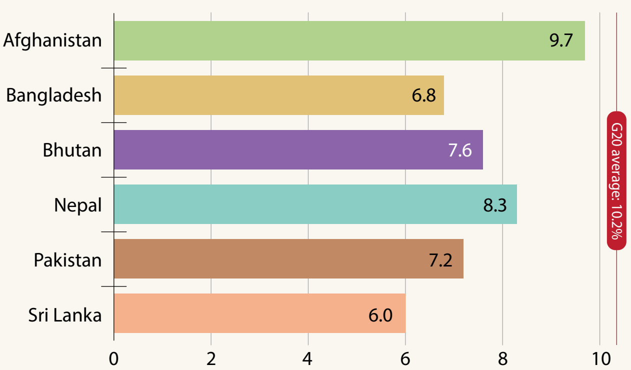
Top five collaborators, 2008–2014 (number of articles)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Afghanistan	USA (97)	UK (52)	Pakistan (29)	Egypt/Japan (26)	
Bangladesh	USA (1394)	Japan (1218)	UK (676)	Malaysia (626)	Rep. of Korea (468)
Bhutan	USA (44)	Australia (40)	Thailand (37)	Japan (26)	India (18)
Maldives	India (14)	Italy (11)	USA (8)	Australia (6)	Sweden/Japan/UK (5)
Nepal	USA (486)	India (411)	UK (272)	Japan (256)	Rep. of Korea (181)
Pakistan	USA (3 074)	China (2 463)	UK (2 460)	Saudi Arabia (1 887)	Germany (1 684)
Sri Lanka	UK (548)	USA (516)	Australia (458)	India (332)	Japan (285)

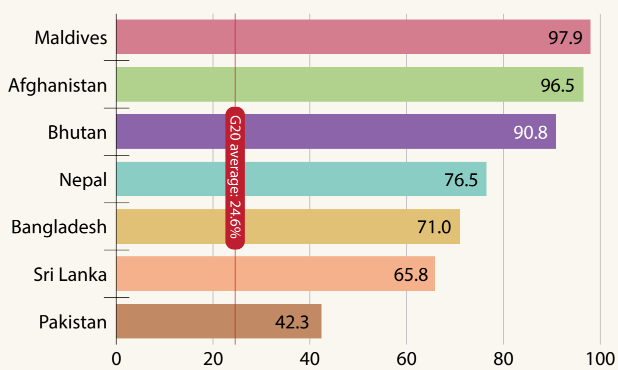
Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

The majority of articles have foreign partners in all but Pakistan

Share of South Asian papers among 10% most-cited, 2008–2012 (%)



Share of papers with foreign co-authors, 2008–2014 (%)



Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix; for nano-articles: statnano.com, see Figure 15.5

COUNTRY PROFILES

AFGHANISTAN

Rapid gains in girls' education

Afghanistan has one of the lowest literacy rates in the world: about 31% of the adult population. Some 45% of men and 17% of women are literate, with wide variations from one province to another. In 2005, the country committed to achieving universal primary education by 2020. Energetic efforts to achieve gender parity have been rewarded by a steep increase in the net enrolment ratio for girls from just 4% in 1999 to an estimated 87% in 2012. By 2012, there was a net intake of 66% of girls and 89% of boys in primary education; boys could expect to complete 11 years of schooling and girls seven years, according to UNESCO's *Education for All Monitoring Report* (2015).

Infrastructure not keeping pace with student rolls

The two key goals of the *National Higher Education Strategic Plan: 2010–2014* devised by the Afghan Ministry of Higher Education were to improve quality and broaden access to higher education, with an emphasis on gender equity. According to a progress report by the same ministry, the number of women students tripled between 2008 and 2014, yet women still represent just one in five students (Figure 21.9). Girls still encounter more difficulties than boys in completing their schooling and are penalized by the lack of university dormitories for women (MoHE, 2013).

The Ministry of Higher Education has largely surpassed its target for raising university enrolment, which doubled between 2011 and 2014 (Figure 21.9). A shortfall in funding has prevented the construction of facilities from keeping pace with the rapid rise in student rolls, however. Many facilities also still need upgrading; there were no functioning laboratories for physics students at Kabul University in 2013, for instance (MoHE, 2013). Only 15% of the US$ 564 million in funding requested of donors by the ministry has materialized since 2010.[2]

Within its *Higher Education Gender Strategy* (2013), the ministry has developed an action plan to augment the number of women students and faculty (Figure 21.9). A pillar of this plan is the construction of women's dormitories. With help from the US State Department, one was completed in Herat in 2014 and another two are planned for Balkh and Kabul. They should house about 1 200 women in total. The ministry also requested funds from the National Priority Programme budget for the construction of ten additional dormitories for 4 000 women students; six of these were completed in 2013.

Part of the growth in university student rolls can be attributed to 'night school', which extends access to workers and young mothers. Having a 'night shift' also makes use of limited space that would otherwise be vacant in the evenings. The night shift is proving increasingly popular, with 16 198 students enrolling in 2014, compared to just 6 616 two years earlier. Women represented 12% (1 952) of those attending evening classes in 2014.

New master's programmes offer more choices

By 2014, the Curriculum Commission had approved the curricular reviews and upgrades for one-third of Afghanistan's public and private faculties. Progress in meeting recruitment goals has also been steady, since staffing is covered by the regular budget allocations (Figure 21.9).

One of the ministry's priorities has been to increase the number of master's programmes (Figure 21.9). This will broaden opportunities for women, in particular, given the difficulties they face in going abroad for master's and PhD training: in the two new master's programmes in education and public administration, half of the students are women. Five of the eight master's degrees granted by Kabul University between 2007 and 2012 were also obtained by women (MoHE, 2013).

Another priority is to increase the share of faculty with a master's degree or PhD. The wider choice of programmes has enabled more faculty to obtain a master's degree but doctoral students still need to study abroad, in order to increase the small pool of PhDs in Afghanistan. The share of master's and PhD-holders has dropped in recent years, as the number of faculty members at Afghan universities has risen; the drop in the share of PhD-holders from 5.2% to 3.8% between 2008 and 2014 was also due to a wave of retirement (Figure 21.9).

Two schemes enable faculty to study abroad. Between 2005 and 2013, 235 faculty members completed their master's degree abroad, thanks to the World Bank's Strengthening Higher Education Programme. In 2013 and 2014, the Ministry of Higher Education's development budget funded the study abroad of 884 faculty working towards their master's degree and 37 faculty enrolled in doctoral programmes.

Grants to revive the research culture

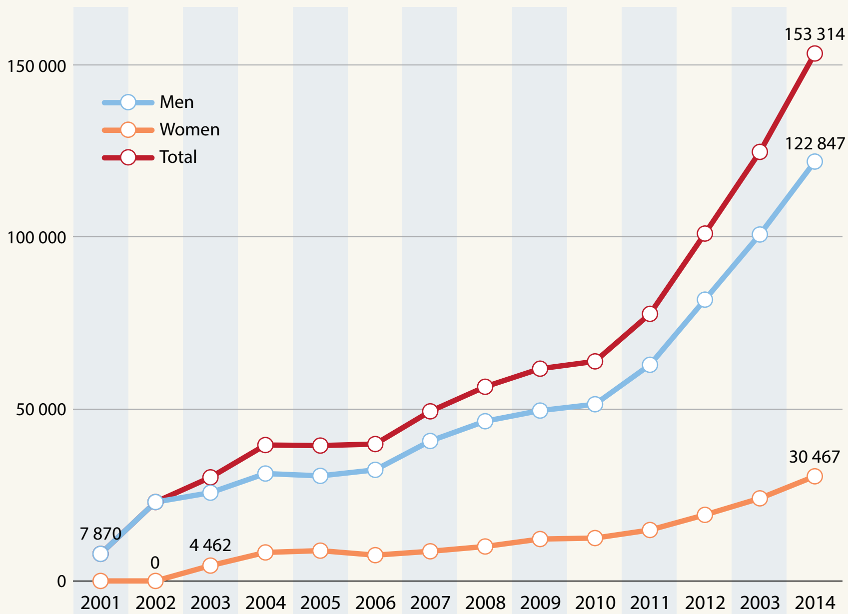
In order to revive Afghanistan's research culture, research units have been installed at 12 universities[3] as part of the World Bank's Higher Education Systems Improvement Project. In parallel, the Ministry of Higher Education developed a digital library in 2011 and 2012 which provides

2. The main donors are the World Bank, USAID, US State Department, NATO, India, France and Germany.

3. Kabul University, Kabul Polytechnic University, Herat University, Nangarhar University, Balkh University, Kandahar University, Kabul Education University, Albiruni University, Khost University, Takhar University, Bamyan University and Jawzjan University.

Figure 21.9: **Afghanistan's ambitious university reform**

Enrolment in public universities doubled between 2011 and 2014



63 837
Afghan university student population in 2010

153 314
Afghan university student population in 2014

20.5%
Share of women university students in 2010

19.9%
Share of women university students in 2014

Afghanistan is making headway towards its higher education targets

	Target	Current situation
National Higher Education Strategic Plan: 2010–2014 (published 2010)	US$ 564 million to be obtained in funding to implement the plan	15% (US$ 84.13 million) received from donors as of 2014
	The number of students at public universities to double to 115 000 by 2015	153 314 students were enrolled in 2014 (target reached)
	Higher education to represent 20% of the education budget by 2015, equivalent to US$ 800 per student in 2014 (corresponding to a budget of US$ 80 million for 2012) and US$ 1 000 by 2015.	The approved budget for 2012 for higher education was US$ 47.1 million, equivalent to US$ 471 per student
	The number of faculty members in public universities to increase by 84% by 2015 to 4 372 and the number of staff by 25% to 4 375	By October 2014, there were 5 006 faculty members; by 2012, there were 4 810 other university staff (target reached)
	The number of master's programmes in Afghanistan to rise	A total of 8 master's programmes were available in 2013 and 25 in 2014 (target reached)
	The share of faculty with a master's degree (31% in 2008) or PhD (5.2% in 2008) to rise	The share of master's degrees and PhDs has dropped slightly, owing to the steep increase in the number of faculty and a wave of retirement among PhD-holders: by October 2014, 1 480 faculty held a master's degree (29.6%) and 192 a PhD (3.8%); 625 faculty members were studying for a master's degree and were expected to graduate by December 2015
	The Ministry of Higher Education to establish Commission on Curriculum	Commission established (target reached); by 2014, it had helped 36% of public faculties (66 out of 182) and 38% of private faculties (110 out of 288) to review and upgrade their curricula
Higher Education Gender Strategy (published 2013)	Women to represent 25% of students by 2014 and 30% by 2015	In 2014, women represented 19.9% of students
	13 women's dormitories to be built	By 2014, seven had been completed
	The number of Afghan women with a master's degree to rise	As of October 2014, 117 women (23% of the total) were pursuing a master's degree in Afghan universities, compared to 508 men
	The proportion of women faculty members to rise to 20% by 2015	By October 2014, 690 faculty members were women (14%), out of a total of 5 006
	The number of women faculty with a master's and PhD degree to rise	By October 2014, 203 women faculty held a master's degree (compared to 1 277 men) and 10 women a PhD

Source: MoHE (2013); MoHE communication in October 2014 all faculty, students and staff with access to about 9 000 academic journals and 7 000 e-books (MoHE, 2013). Participation in research is now a requirement for the promotion of faculty at every level. In the first round of competitive bidding in 2012, research grants were approved for projects proposed by faculty members from Kabul University, Bamyan University and Kabul Education University. Projects concerned the use of IT in learning and research; challenges of the new middle school mathematics curriculum; the effect of automobile pollution on grapevines; integrated management of nutrients in wheat varieties; traditional ways of blending concrete; and the effect of different methods of collecting sperm from bulls (MoHE, 2013).

The research committee established at each of the 12 universities approved 9 research proposals in 2013 and a further 12 in 2014. The ministry is currently working with the Asian Institute of Technology in Thailand to develop joint educational programmes. As part of this collaboration, 12 university faculty members were seconded to the institute in 2014. Work began on drafting a national research policy the same year (MoHE, 2013).

Financial autonomy for universities?

A major goal of the Ministry of Higher Education is to grant some financial autonomy to universities, which are currently not entitled to charge tuition fees or keep any income. The ministry cites a World Bank study from 2005 of Pakistan, which repealed similar restrictive legislation about a decade ago. 'Now, Pakistani universities, on average, earn 49% of their budget (with some as high as 60%) from income they raise and gifts,' observes the ministry (MoHE, 2013).

The aim of the reform is to foster entrepreneurship, university–industry ties and the universities' capacity to provide services. The ministry has prepared a proposal which would allow higher education institutions to keep funds that they earn from entrepreneurial activities, such as drugs analysis done by the Faculty of Pharmacy at Kabul University for the Ministry of Public Health. They would also be able to keep income from night courses and donations from benefactors and alumni. In addition, they would be entitled to set up foundations which could accumulate funds for major projects (MoHE, 2013).

The ministry's position was vindicated by the outcome of a pilot project implemented in 2012 which gave universities in Kabul greater authority over procurement and expenditure below a certain financial threshold. The ministry's plans have been put on hold, however, by the failure of parliament to pass the Higher Education Law, which was approved by the Education Committee in 2012.

BANGLADESH

Great strides in education

The *Bangladesh Education Sector Review 2013* commissioned by the World Bank recognizes significant achievements in primary education since 2010. Net enrolment rates have risen steadily, attaining 97.3% in 2013. Over the same period, the completion rate at primary level rose from 60.2% to 78.6%. Gender parity at both primary and secondary levels has been achieved well ahead of the MDG target set for 2015. The percentage of girls attending school has even surpassed that of boys in recent years.

The quality of education has also improved: according to the Bangladesh Bureau of Educational Information and Statistics, class sizes in secondary schools reportedly shrank from 72 to 44 pupils per class between 2010 and 2013. Repetition rates at primary school level dropped from 12.6% to 6.9% over the same period, with a parallel improvement in the pass rate for the Secondary School Certificate examination and the closing of the gender gap for this indicator. By mid-2014, over 9 000 primary school classrooms had been built or rehabilitated, with the installation of water and sanitary facilities.

Among the drivers of this positive change, the *Education for All 2015 National Review* identifies the conditional cash transfer to children from poor families at primary level and to rural girls at secondary level; the use of ICTs in education; and the distribution of free textbooks to schools, which can also be downloaded free of charge from the government's e-book website.[4]

Among the remaining challenges identified by the *Education Sector Review* (2013), about five million children are still not attending school and the rate of progression from primary to secondary school (60.6% in 2013) has not improved. The review estimates that education plans should target the hardest-to-reach populations. It also pinpoints the need for a substantial rise in budgetary allocations to secondary and higher education. In 2009, the last year for which data are available, just 13.5% of the education budget went to higher education, representing 0.3% of GDP (Figure 21.3).

Despite low levels of funding, enrolment in bachelor's and master's degrees rose from 1.45 million to 1.84 million between 2009 and 2012, with particularly strong growth in S&T fields. Growth was most impressive in engineering (+68%), where enrolment in PhD programmes almost tripled between 2009 and 2012 (Table 21.2). This augurs well for the government's strategy of fostering industrialization and economic diversification. Some 20% of university students are enrolled in a master's programme, one of the highest ratios in Asia, but only 0.4% enrol in a PhD programme (see Figure 27.5).

4. See: www.ebook.gov.bd

ICTs at heart of education policies

After several unsuccessful attempts, the first formal *National Education Policy* was adopted in 2010. Key strategies include providing one year of pre-primary schooling for all children; extending compulsory primary education from Grade 5 to Grade 8 by 2018; expanding vocational/technical training and curricula; making all pupils ICT-literate by the completion of primary school; and updating the syllabuses of higher education to meet international standards.

Both the *National Education Policy* and *National Information and Communication Policy* (2009) underscore the importance of using ICTs in education. For instance, the *National Education Policy* makes ICTs a compulsory subject of vocational and technical education curricula; universities are to be equipped with computers and relevant curricula; and training facilities specializing in ICTs are to be developed for teachers.

The *Master Plan for ICT in Education* for 2012 –2021 sets out to generalize the use of ICTs in education. ICTs were introduced in 2013 as a compulsory subject for higher secondary school pupils intending to sit public examinations in 2015. According to the Bangladesh Bureau of Educational Information and Statistics, the share of secondary schools with computer facilities rose from 59% to 79% between 2010 and 2013 and the percentage of secondary schools with internet shot up from 18% to 63%.

Science and ICTs for middle-income status by 2021

The *Perspective Plan of Bangladesh to 2021* was finalized in 2012 to operationalize the country's blueprint for becoming a middle-income economy by 2021, *Vision 2021*; one thrust of the *Perspective Plan* is to improve the quality of education, with an emphasis on science and technology. Curricula are to be upgraded and the teaching of mathematics, science and information technology encouraged. 'An innovative people will be the backbone of the envisioned society in 2021,' observes the *Plan*, thanks to 'a strong learning system from pre-primary to university levels and the application of research and STI.' Innovation is to be promoted in education and at work. Vast efforts will be made to develop IT through the Digital Bangladesh programme, one of the pillars of *Vision 2021*, in order to foster a 'creative' population (Planning Commission, 2012).

In order to provide the necessary impetus to achieve a Digital Bangladesh by 2021, the Ministry of Science and Information and Communication Technology has been divided into two separate ministries. In its medium-term strategy for 2013–2017, the new Ministry of Information and Communication Technology evokes the development of a high-tech park, an IT village and a software technology park. To this end, the Bangladesh High-tech Authority was created in 2010 by act of parliament. The ministry is currently revising the *National Information and Communication Policy* (2009) and the Copyright Act (2000) to ensure that the rights of local software designers are protected.

The country's first *Science and Technology Policy* was adopted in 1986. It was revised between 2009 and 2011 and is currently under revision once more, in order to ensure that it contributes effectively to realizing the goals of *Vision 2021* (Hossain *et al.*, 2012). Some key targets of *Vision 2021* are to (Planning Commission, 2012):

- establish more institutes of higher learning in science and technology;
- raise GERD 'significantly' from the current level of 0.6% of GDP;
- increase productivity in all spheres of the economy, including micro-enterprises and small and medium-sized enterprises (SMEs);
- establish a National Technology Transfer Office (Box 21.3);

Box 21.3: Quality higher education for Bangladesh

The Higher Education Quality Enhancement Project (2009–2018) funded by the World Bank aims to improve the quality and relevance of the teaching and research environment in Bangladesh by encouraging both innovation and accountability within universities and by enhancing the technical and institutional capacity of the higher education sector.

The mid-term project review reported satisfactory progress in 2014. This included connecting 30 public and private universities to the Bangladesh Research and Education Network and continuous funding allocated on the basis of the performance of academic research projects which had already received funding.

This project is supported by a competitive funding mechanism known as the Academic Innovation Fund (AIF). AIF has clear selection criteria and allocates resources through four competitive funding streams: improvement of teaching and learning and enhancement of research capabilities; university-wide innovation, including the establishment of a National Technology Transfer Office; and collaborative research with industry. In 2014, 135 sub-projects were awarded AIF grants. Earlier projects have also reported satisfactory progress.

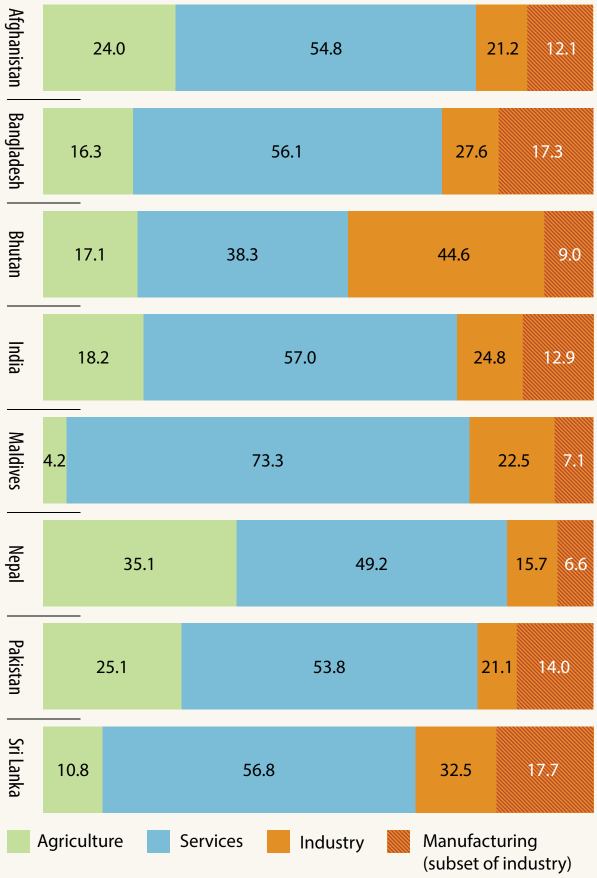
Source: World Bank

- attain self-sufficiency in food production;
- reduce the proportion of people employed in agriculture from 48% to 30% of the labour force;
- raise the contribution of manufacturing to about 27% of GDP and that of industry to about 37% of GDP (Figure 21.10);
- make ICT education compulsory at secondary level by 2013 and at primary level by 2021;
- increase teledensity to 70% by 2015 and 90% by 2021.

The Ministry of Science and Technology describes its current mission as being to:

- expand peaceful use of nuclear energy through the establishment of an atomic power plant and centres of nuclear medicine;
- foster research on biotechnology and develop related human resources;
- develop environment-friendly, sustainable technology for the poor through R&D, such as arsenic-free water, renewable energy and energy-saving cookers;
- develop infrastructure for conducting oceanographic research to enable use of the vast resources of the Bay of Bengal;
- enable the Scientific Documentation Centre to furnish relevant S&T and industrial data to policy-makers and decision-makers; and
- inculcate a scientific attitude in the general public and create interest in astronomy through entertainment.

Figure 21.10: **GDP per economic sector in South Asia, 2013**



Source: World Bank's World Development Indicators, April 2015

Box 21.4: **Agricultural technology to boost productivity in Bangladesh**

The *Perspective Plan of Bangladesh to 2021* observes that 'flood-resistant crops are a must for the country with chronic floods, little arable land and a rapidly growing population' (1.2% annual growth in 2014). It also acknowledges that, for Bangladesh to become a middle-income country by 2021, industrial expansion must go hand-in-hand with more productive agriculture.

The National Agricultural Technology Project funded by the World Bank (2008–2014) set out to improve yields through research and technology transfer. The World Bank funded the research grants awarded by the government-sponsored Krishi Gobeshana Foundation (Agricultural Research Foundation), which had been set up in 2007. Some of these research projects developed the genotypes of spices, rice and tomato for release by the National Seed Board. Research focused on promoting climate-smart agriculture and agro-ecological approaches to farming in demanding ecosystems, such as floodplains and saline soils. By 2014, the project had clocked up the following achievements:

- 47 demonstrated new technologies had been adopted by 1.31 million farmers;
- 200 applied research projects had been funded;
- Scholarships had been awarded to 108 male and female scientists to pursue higher studies in agriculture;
- 732 farmers information and advisory centres had been established;
- 400 000 farmers had been mobilized into over 20 000 common interest groups linked to markets; and
- 34 improved post-harvest technologies and management practices had been adopted by over 16 000 farmers.

Source: World Bank; Planning Commission (2012)

Revamping industry

Although Bangladesh's economy is based predominantly on agriculture (16% of GDP in 2013), industry contributes more to the economy (28% of GDP), largely through manufacturing (Figure 21.10). The *National Industrial Policy* (2010) sets out to develop labour-intensive industries. By 2021, the proportion of workers employed in industry is expected to double to 25%. The policy identifies 32 sectors with high-growth potential. These include established export industries such as the ready-made garment sector, emerging export industries such as pharmaceutical products and SMEs.

The *National Industrial Policy* also recommends establishing additional economic zones, industrial and high-tech parks and private export processing zones to drive rapid industrial development. Between 2010 and 2013, industrial output already grew from 7.6% to 9.0%. Exports remain largely dependent on the ready-made garment sector, which contributed 68% of all exports in 2011–2012, but other emerging sectors are growing, including shipbuilding and the life sciences. This industrialization policy is in line with the current Sixth *Five-year Plan* (2011–2015), which sees industrialization as a means of reducing poverty and accelerating economic growth.

Three months after the Rana Plaza tragedy in April 2013, in which more than 1 100 mainly female workers in the garment industry perished when a multi-storey factory collapsed, the International Labour Organization, European Commission and the Governments of Bangladesh and the USA signed the Sustainability Compact agreement. This agreement set out to improve labour, health and safety conditions for workers and to encourage responsible behaviour by businesses in the Bangladeshi ready-made garment industry.

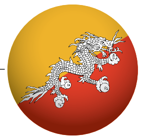
The government has since amended the Labour Act. The amendments include the adoption of a national occupational safety and health policy and standards for safety inspections and the strengthening of laws in support of freedom of association, collective bargaining and occupational safety and health. Safety inspections have been performed in export-oriented garment factories and public factory inspection services have been given more resources. The findings of their ongoing inspections are being made public. For its part, the private sector has put in place an *Accord on Factory and Building Safety in Bangladesh* and an *Alliance for Bangladesh Worker Safety* to facilitate factory inspections and improve working conditions.

Poor infrastructure a deterrent for investors

According to the *World Investment Report 2014*, Bangladesh was one of the top five host countries for FDI in South Asia in 2012 and 2013. FDI net inflows nearly doubled from US$ 861 million in 2010 to US$1 501 million in 2013. Although FDI outflows were low, they did increase from US$ 98 million in US$ 130 million over the same period.

However, UNCTAD's *Investment Policy Review* of Bangladesh (2013) observed that, when FDI inflows were analysed relative to population and as a share of GDP, they were consistently lower in Bangladesh than in some more populous countries such as India and China. The FDI stock of Bangladesh was even lower in 2012 than that of smaller countries such as Cambodia and Uganda. The *Investment Policy Review* found that FDI was instrumental in mobile telephony, substantial in power generation and catalytic but not predominant in garments. The study also found that the poor quality of infrastructure was a major deterrent for potential investors. It suggested that better infrastructure and an improved regulatory framework would foster sustainable investment through FDI.

BHUTAN



Happiness in times of social change

The Kingdom of Bhutan's approach to all aspects of national development is guided by its focus on the overarching concept of gross national happiness. This concept is encapsulated in *Bhutan 2020: A Vision for Peace, Prosperity and Happiness,* the country's development blueprint since 1999. *Bhutan 2020* identifies five principal development objectives: human development; culture and heritage; balanced and equitable development; governance; and environmental conservation.

The Bhutanese have the third-highest level of income in South Asia after the Maldives and Sri Lanka. Per-capita GDP rose steadily between 2010 and 2013 (Figure 21.1). Over the past decade, the traditional, mainly agricultural economy has become more industrialized (Figure 21.10). As the contribution from other sectors has risen, the role of agriculture has declined.

Traditionally, Bhutanese women have held a relatively elevated position in society; they tend to have greater property rights than elsewhere in South Asia, with women rather than men inheriting property in some areas. Industrial development over the past decade appears to have had a negative impact on the traditional place of women in society and their participation in the labour force. The employment gap had been narrowing since 2010 but started widening again in 2013, by which time 72% of men were in gainful employment, compared to 59% of women, according to the *National Labour Force Survey Report (2013).* The unemployment rate nevertheless remains low, at just 2.1% of the population in 2012.

A focus on the green economy and IT

Bhutan's private sector has thus far played a limited role in the economy. The government plans to change this by improving the investment climate through policy and institutional reform and by developing the IT sector, in particular. In 2010, the government revised its *Foreign Direct Investment Policy* (dating from 2002) to bring it into line with its *Economic Development Policy* adopted the same year.

The *Foreign Direct Investment Policy* (2010) identifies the following priority areas for FDI:

- Development of a green and sustainable economy;
- Promotion of socially responsible and ecologically sound industries;
- Promotion of cultural and spiritually sensitive industries;
- Investment in services which promote Brand Bhutan; and
- Creation of a knowledge society.

The policy identifies the following sectors and sub-sectors as being priority areas for investment that merit fast-track approval, among others:

- *Agro-based production*: organic farming; biotechnology, agro-processing, health food, etc.;
- *Energy*: hydropower, solar and wind energy;
- *Manufacturing*: electronics, electrical, computer hardware and building materials.

In 2010, the government published its *Telecommunications and Broadband Policy*. The policy announces the adoption of a *Human Resource Development Plan* to help the ICT sector grow. It also foresees collaboration with the university sector to bridge the gap between curricula and the needs of the IT sector. A revised version of the policy was published in 2014 to reflect the dynamism of this rapidly evolving sector.

Bhutan's first IT park

The Private Sector Development Project (2007–2013) funded by the World Bank is also helping to develop the IT industry. It has three thrusts: fostering the development of enterprises in the IT services sector; enhancing related skills; and improving access to finance. The project has spawned the first IT park in Bhutan, Thimphu TechPark, which was commissioned in May 2012. This is an unprecedented public–private partnership for infrastructure development in Bhutan. The Bhutan Innovation and Technology Centre, which houses Bhutan's first business incubator, has since been established at Thimpu Tech Park.[5]

Industrialization highlights skills mismatch

Illiteracy has long been an issue in Bhutan. In 2010, 53.6% of the labour force was illiterate, 55% of whom were women. Overall illiteracy had declined to 46% by 2013 but remains extremely high. Adding to this picture, only 3% of employees hold a university degree.

In 2012, skilled agricultural and fisheries workers represented 62% of the labour force, compared to only 5% in manufacturing and 2% in mining and quarrying. The agricultural sector, with its inherent bias towards entrepreneurial self-employment, offers untapped potential for developing more value-added products and economic diversification. Appropriate skills training and vocational education will be necessary to nurture the country's industrial development.

The Bhutanese government's eleventh *Five-year Plan* (2013–2018) acknowledges the current shortage of skills in highly specialized professions and the mismatch between curricula and the skills required by industry. It also highlights the challenge posed by the limited resources for developing school infrastructure and the low interest in teaching as a profession: nearly one in ten (9%) teachers was an expatriate in 2010, although this share had dropped to 5% by 2014.

Unlike in other South Asian countries, there are no major gender inequality issues in the Bhutanese education system; primary school enrolment of girls is even higher than that of boys in many urban areas. Net primary school enrolment had reached 95% by 2014, thanks to the development of the secular school system, which has provided pupils living in remote areas with access to education. The government also aims to use ICTs to improve the quality of education (Box 21.5).

Although 99% of children acceded to secondary level education in 2014, three out of four later dropped out (73%). The *Annual Education Statistics Report* (2014) suggests that

5. See:www.thimphutechpark.com/bitc

Box 21.5: Using ICTs to foster collaborative learning in Bhutan

Launched in March 2014, the i-school project in Bhutan is a joint initiative of the Ministry of Education, Bhutan Telecom Limited, Ericsson and the Indian government. The project strives to give children quality education through the use of mobile broadband, cloud computing and the like. The collaborative learning and teaching made possible through this project is based on connectivity to other schools across the country and around the world.

Six schools are participating in the first 12-month pilot phase of the project. Two are located in Thimphu, one in Punakha, one in Wangduephodrang, one in P/Ling and another in Samtse.

Source: compiled by authors

many may be opting for vocational training at this stage of their education. The *National Human Resource Development Policy* (2010) announced that vocational education would be introduced in schools from Grades 6 to 10 and that public–private partnerships would be put in place to improve the quality of training at vocational and technical institutes.

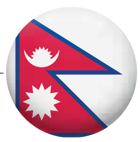
A national council proposed to frame research

The *Tertiary Education Policy* (2010) fixed the target of raising university enrolment from 19% to 33% of 19 year-olds by 2017. The policy observed that mechanisms needed putting in place to measure the level of research activity in Bhutan and recommended an initial scoping exercise. The policy identified the following challenges for research:

- National priorities for research need to be established and a system for determining such a strategy needs to be put in place. Different organizations undertake research but it is not based on an agreed understanding of national priorities.
- Research needs to be encouraged through funding, direction, career structures and access to networks of other researchers. It is also crucial to establish easy connections between research centres with government and industry. Funding could be of two types: seed funds to develop a research culture and more substantial funds to encourage research that attempts to address national problems.
- Facilities, including laboratories and libraries with up-to-date information are needed for research. Currently, there is no government organization responsible for overseeing the interaction between all of the actors within the research and innovation system.

To overcome these shortcomings, the policy stated that a National Council for Research and Innovation would be established. As of 2015, this was not the case.

REPUBLIC OF MALDIVES



Special circumstances call for sustainable solutions

The Republic of Maldives remains heavily reliant on fossil fuels, despite the obvious advantages of local energy generation for the archipelago. A number of initiatives have been taken to promote the uptake of solar and wind–diesel hybrid systems for electricity generation, which are financially feasible (Van Alphen *et al.,* 2008). A study by the Republic of Maldives (2007a) identified a number of constraints, including deficient regulatory frameworks which weaken public–private partnerships and limited technical and managerial capacities in energy transmission and distribution. Similar conclusions can be drawn for the transportation sector, which is fast expanding in the islands due to tourism (Republic of Maldives, 2007b), or the sustainability of the capital, Malé, considered one of the world's most crowded metropolises.

Signs of a greater focus on science

The Maldives has had a tertiary learning institution since 1973 in the form of an Allied Health Services Training Centre. First transformed into the Maldives College of Higher Education in 1999 then into the Maldives National University in February 2011, it remains the country's only tertiary public degree-granting institution. In 2014, the university inaugurated its Faculty of Science, with the introduction of degree programmes in general sciences, environmental science, mathematics and information technology. In addition, postgraduate programmes on offer include a Master of Science in Computing and a Master of Science in Environmental Management. The university also has its own journal, the *Maldives National Journal of Research*, but the focus appears to be on pedagogy rather than the university's own research.

Research output remains modest, with fewer than five articles being published each year (Figure 21.8). The fact that nearly all publications in the past decade involved international collaboration nevertheless bodes well for the development of endogenous science.

A commitment to education spending

The Maldives devoted 5.9% of GDP to education in 2012, the highest ratio in the region. It faces a number of challenges in developing its human capital that have been compounded by the political turmoil since 2012. Other challenges include the large share of expatriate teachers and the mismatch between curricula and the skills employers need.

Although the Maldives had achieved universal net primary enrolment by the early 2000s, this had fallen back to 94% by 2013. Nine out of ten pupils went on to secondary school (92.3%) in 2014 but only 24% stayed on at the higher secondary level. There are more girls than boys at the primary and lower secondary levels but boys overtake girls at the higher secondary level.

The Ministry of Education is eager to improve the quality of education. Between 2011 and 2014, UNESCO implemented a project in the Maldives for Capacity-building in Science Education, with financial support from Japan and the involvement of the Centre for Environment Education in India. The project developed teaching guides and prepared modules and hands-on activity kits to foster creative thinking and the scientific method. In-service teacher training was also organized for students at the Maldives National University.

The Ministry of Education and Ministry of Human Resources, Youth and Sport began implementing a one-year Hunaru ('skills') Project for vocational and technical training in 2013. The aim is to train 8 500 young people in 56 occupational fields, with the government paying a fixed amount per student. Both public and private institutions can apply to run these courses.

The government is intensifying public–private partnerships by offering land and other incentives to private companies to set up institutions offering higher education in selected locations. One such partnership was under way on Lamu Atoll in 2014, where the Indian company Tata has agreed to set up a medical college and to develop a regional hospital.

NEPAL

Moderate growth, falling poverty

Despite its prolonged political transition since the end of the civil war in 2006, Nepal has registered a moderate rate of growth averaging 4.5% over 2008–2013, as compared to the low-income country average of 5.8%. Nepal was hardly affected by the global financial crisis of 2008–2009, as it remains poorly integrated in global markets. Exports of goods and services as a share of GDP nevertheless fell from 23% to 11% between 2000 and 2013. Contrary to what one would expect from a country at Nepal's stage of development, the share of manufacturing has also gone down slightly in the five years to 2013, to just 6.6% of GDP (Figure 21.10).

The country is on track to reach a number of MDGs, particularly those in relation to the eradication of extreme poverty and hunger, health, water and sanitation (ADB, 2013). Nepal will need to do much more, though, to reach the MDGs relating to employment, adult literacy, tertiary education or gender parity in employment, which are more germane to science and technology. The country has some key advantages, notably high remittances from abroad – 20.2% of GDP between 2005 and 2012 – and the country's proximity to high-growth emerging market economies such as China and India. Nepal lacks an effective growth strategy, though, to harness these advantages to accelerated development. The Asian Development Bank's *Macroeconomic Update of Nepal* underlined in February 2015 the deficient investment in R&D and innovation by the private sector as being key constraints to supply capacity and competitiveness.

The government is cognizant of the problem. Nepal has had a specific ministry in charge of science and technology since 1996. The responsibilities of this ministry have been combined with those of the environment since 2005. Partly as a result, the country's modest efforts in science and technology are heavily focused on environmental issues, which is broadly defensible, given Nepal's high vulnerability to natural disasters and climate-related risks. The current *Three-Year Plan* (2014–2016) includes a number of priority areas that are relevant to S&T policies and outcomes (ADB, 2013, Box 1):

- Increasing access to energy, especially a rural electrification programme based on renewable sources (solar, wind, and hybrids) and miniature run-of the river hydropower plants;
- Increasing agricultural productivity; and
- Climate change adaptation and mitigation.

Realizing these goals, while addressing Nepal's competitiveness and growth challenges more broadly, will depend heavily on the uptake of clean and environmentally sound technologies. Successful technology absorption will, in turn, be conditional on the adequate development of local S&T capacities and human resources.

Three new universities since 2010

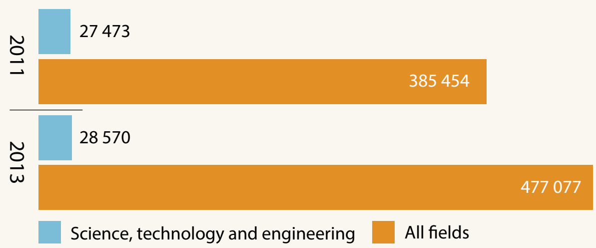
The *UNESCO Science Report 2010* attributed the lack of development in S&T capabilities to the low priority given to education in basic sciences, at the expense of applied fields such as engineering, medicine, agriculture and forestry. Nepal's oldest university, Tribhuvan University (1959) has since been joined by eight other institutions of higher learning, the last three of which were established in 2010: the Mid-western University in Birendranagar, the Far-western University in Kanchanpur and Nepal Agriculture and Forestry University in Rampur, Chitwan.

Despite this development, official statistics suggest that enrolment in S&T fields is not progressing as fast as tertiary enrolment overall. Science and engineering students accounted for 7.1% of the student body in 2011 but only 6.0% two years later (Figure 21.11).

Striking a balance between basic and applied sciences

It is justifiable for a low-income country like Nepal to focus on applied research, provided it has sufficient connectivity to be able to tap into basic scientific knowledge generated elsewhere. At the same time, a greater capability in basic

Figure 21.11: **Students enrolled in higher education in Nepal, 2011 and 2013**



Source: UNESCO Institute for Statistics, June 2015

sciences would help the country to absorb and apply knowledge and inventions produced abroad. The exact balance of policy focus in this area is a difficult call to make in the absence of a more in-depth review of Nepal's innovation constraints and options. Moreover, whereas the *UNESCO Science Report 2010* and national studies (such as NAST, 2010) have advocated a greater focus on basic research in Nepal, some of the country's more recent policy pronouncements establish the priority of learning in applied science and technology over pure science; this is the case, for example, of the declared objectives of the planned Nanotechnology Research Centre (Government of Nepal, 2013a).

A leap forward in Nepal's R&D effort

The *UNESCO Science Report 2010* had also underlined the low level of private sector investment in R&D. Half a decade on, Nepal still does not measure the business sector's R&D effort. However, official statistics suggest a leap in the government budget for R&D since 2008, from 0.05% to 0.30% of GDP in 2010, a greater effort than that of the relatively richer economies of Pakistan and Sri Lanka. Considering that 25% of researchers (by head count) worked in the business sector, higher education or non-profit sector in 2010, total GERD in Nepal is likely to be closer to 0.5% of GDP. Indeed, the data also suggest a 71% increase[6] in the number of researchers between 2002 and 2010 to 5 123 (or 191 per million population), as well as a doubling of technicians over the same period (Figure 21.7).

Potential to attract more the diaspora

The *UNESCO Science Report 2010* had noted the low number of PhD students in Nepal and the modest level of scientific production. In 2013, there were still only 14 PhD degrees awarded in Nepal.

At the same time, Nepal has a relatively large tertiary student population abroad, numbering 29 184 in 2012. That year, the Nepalese represented the eighth-largest foreign student population in natural and social sciences and engineering disciplines in the USA[7] and the sixt- largest in Japan, according to the National Science Foundation's *Science & Engineering Indicators, 2014*. Between 2007 and 2013, 569 Nepalese nationals earned PhDs in the USA. Likewise, there are sizeable Nepalese tertiary student communities in Australia, India, the UK and Finland[8]. There is a potential to harness this expatriate talent for the development of Nepal's future S&T potential, provided the right circumstances and momentum can be provided to woo them back home.

6. although there was a break in the data series between 2002 and 2010

7. after China, the Republic of Korea, Saudi Arabia, India, Canada, Viet Nam and Malaysia

8. www.uis.unesco.org/Education/Pages/international-student-flow-viz.aspx

Ambitious plans to 2016

The Nepalese government is confident that the period of the *Twelfth Three-Year Plan* covering 2010–2013 has made a difference. This period has been marked by the start of DNA testing in Nepal, the establishment of a science museum, the expansion of forensic science services, the consolidation of research laboratories and the inception of three-cycle studies (Government of Nepal, 2013b). The government also claims to have minimized brain drain.

In the field of disaster risk reduction, two projects were implemented within the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia. The first sought to develop a flood forecasting system for Nepal (2009–2011) and the second to expand climate risk management through technical assistance. As events so cruelly recalled in April 2015, Nepal does not have an earthquake early warning system which would have given citizens forewarning of about 20 seconds of the impending disaster. Moreover, the number of lives lost in recent floods, despite the existence of a flood warning system, indicates the need for a more integrated solution.

The *Thirteenth Three-Year Plan* covering 2013–2016 goes a step farther by articulating specific objectives to enhance the contribution of science and technology to economic development, including by:

- checking and reversing the brain drain of scientists and technicians;
- encouraging the formation of research and development units within industries;
- harnessing atomic, space, biological and other technologies, as required, for development;
- developing capacities in biological sciences, chemistry and nanotechnologies, in particular to benefit from Nepal's rich biodiversity; and
- mitigating the effects of natural disasters and climate change, through early warning systems and other mechanisms, in part through the use of space technology.

In this context, the Ministry of Science, Technology and Environment plans to set up four technology centres in the near future, namely a National Nuclear Technology Centre, a National Biotechnology Centre, a National Space Technology Centre and a National Nanotechnology Centre. Some of these research areas have obvious relevance for Nepal's sustainable development, such as the use of space-related technologies for environmental surveying and disaster monitoring or weather forecasting. The Nepalese government needs to elaborate further the rationale and context behind other initiatives, such as its plans for nuclear technology development.

PAKISTAN

Plans to boost higher education spending

Since 2010, Pakistan's economy has remained relatively depressed, owing to the uncertain security situation and ongoing political power crisis. More than 55 000 civilians and military personnel have perished in hundreds of major and minor terrorist attacks across major urban centres since 2003.[9] Between 2010 and 2013, Pakistan's annual growth rate averaged 3.1%, compared to 7.2% in India and 6.1% in Bangladesh. The economic impact of the security situation manifests itself in consistently falling investment levels: FDI inflows accounted for 2.0% of GDP in 2005 but only 0.6% in 2013. In addition, tax revenue stood at 11.1% of GDP in 2013, according to the World Bank, one of the lowest rates in the region, limiting the government's ability to invest in human development.

During the 2013–2014 fiscal year, government spending on education stood at merely 1.9% of GDP, just 0.21% of which was earmarked for higher education. Education spending has shrunk each year since peaking at 2.75% of GDP in 2008. As part of Pakistan's effort to create a knowledge economy, *Vision 2025* (2014) has fixed the target of achieving universal primary school enrolment and raising university enrolment from 7% to 12% of the age cohort and the number of new PhDs per year from 7 000 to 25 000 over the next decade. In order to reach these targets, the government has proposed devoting at least 1% of GDP to higher education alone by 2018 (Planning Commission, 2014).

Vision 2025 was developed by the Ministry of Planning, Development and Reform and approved by the National Economic Council in May 2014. It identifies seven pillars for accelerating the pace of economic growth, including through the creation of a knowledge economy:

- Putting people first: developing human and social capital;
- Achieving sustained, indigenous and inclusive growth;
- Governance, institutional reform and modernization of the public sector;
- Energy, water and food security;
- Private sector-led growth and entrepreneurship;
- Developing a competitive knowledge economy through value addition; and
- Modernization of transportation infrastructure and greater regional connectivity.

9. according to the Institute for Conflict Management, South Asia Terrorism Portal; see: www.satp.org/satporgtp/icm/index.html.

Within this vision, the first and sixth pillars are directly relevant to the STI sector, whereas the overall global competitiveness of the country will depend on innovation in certain competitive sectors. Moreover, government-led infrastructure projects being planned as part of this vision include the construction of a highway linking Lahore and Karachi, the Peshawar Northern Bypass, Gawadar Airport and the Gawadar Free Economic Zone.

The government plans to reconfigure the current energy mix to overcome power shortages. About 70% of energy is generated using furnace oil, which is costly and has to be imported. The government plans to convert furnace oil plants to coal and is investing in several renewable energy projects, which are one of the priorities of *Vision 2025*.

Energy is one focus of the new Pakistan–China Economic Corridor Programme. During the Chinese president's April 2015 visit to Pakistan, 51 memoranda of understanding were signed between the two governments for a total of US$ 28 billion, much of it in the form of loans. Key projects within this programme include developing clean coal-based power plants, hydropower and wind power, a joint cotton biotech laboratory to be run by the two ministries of science and technology, mass urban transportation and a wide-ranging partnership between the National University of Modern Languages in Islamabad and Xinjiang Normal University in Urumqi. The programme takes its name from the planned corridor that is to link the Pakistani port of Gwadar on the Sea of Oman to Kashgar in western China near the Pakistani border, through the construction of roads, railway lines and pipelines.

In January 2015, the government announced two policies to facilitate the deployment of solar panels across the country, including the removal of taxes on imports and sales of solar panels. After these taxes were introduced in 2013, the volume of solar panel imports had shrunk from 350 MW to 128 MW. Through the second policy, the State Bank of Pakistan and the Alternative Energy Development Board will allow home-owners to leverage their mortgage to pay for the installation of solar panels for a value of up to five million rupees (*circa* US$50 000), with comparatively low interest rates (Clover, 2015).

Pakistan's first STI policy

Among the most critical determinants for the success of any country's STI sector are the institutional and policy systems responsible for managing relevant public policies. The Federal Ministry of Science and Technology has overseen the S&T sector since 1972. However, it was not until 2012 that Pakistan's first *National Science, Technology and Innovation Policy* was formulated: this was also the first time that the government had formally recognized innovation as being a long-term strategy for driving economic growth. The policy principally emphasizes the need for human resource development, endogenous technology development, technology transfer and greater international co-operation in R&D. However, it is not clear whether any part of the policy has been implemented since its release.

The policy was informed by the technology foresight exercise undertaken by the Pakistan Council for Science and Technology from 2009 onwards. By 2014, studies had been completed in 11 areas: agriculture, energy, ICTs, education, industry, environment, health, biotechnology, water, nanotechnology and electronics. Further foresight studies are planned on pharmaceuticals, microbiology, space technology, public health (see a related story in Box 21.6), sewage and sanitation, as well as higher education.

R&D intensity to triple by 2018

Following the change of government in Islamabad after the May 2013 general election, the new Ministry of Science and Technology issued the draft *National Science, Technology and Innovation Strategy 2014–2018,* along with a request for comments from the public. This strategy has been mainstreamed into the government's long-term development plan, *Vision 2025*, a first for Pakistan. The central pillar of the draft *National Science, Technology and Innovation Strategy* is human development. Although the pathway to implementation is not detailed, the new strategy fixes a target of raising Pakistan's R&D spending from 0.29% (2013) to 0.5% of GDP by 2015 then to 1% of GDP by the end of the current government's five-year term in 2018. The ambitious target of tripling the GERD/GDP ratio in just seven years is a commendable expression of the government's resolve but ambitious reforms will need to be implemented concurrently to achieve the desired outcome, as greater spending alone will not translate into results.

Little change in the R&D sector

In Pakistan, the government is very present in the R&D sector, both through public investment in defence and civilian technologies and through state-operated bodies. According to the R&D survey undertaken by the Pakistan Council for Science and Technology in 2013, the government's R&D organizations receive nearly 75.3% of national R&D spending.

The share of the population engaged in R&D dropped between 2007 and 2011, be they researchers or technicians. However, growth then picked up between 2011 and 2013; these trends correlate with the relatively static levels of government spending in the R&D sector through its various organizations, which has not kept pace with economic growth.

In the public sector, about one in four researchers are engaged in the natural sciences, followed by the agricultural sciences and engineering and technology. Almost one in three researchers were female in 2013. Women made up half of researchers in medical sciences, about four out of ten in natural sciences but only one in six engineers and one in ten agricultural scientists. The great majority of state researchers work in the higher education sector, a trend that has become more pronounced since 2011 (Table 21.4).

The fact that the business enterprise sector is not surveyed does not augur well for monitoring progress towards a knowledge economy. Moreover, neither *Vision 2025,* nor the draft *National Science, Technology and Innovation Strategy 2014– 2018* proposes strong incentives and clear roadmaps for fostering the development of industrial R&D and university–industry ties.

Box 21.6: **An app tracks a dengue outbreak in Pakistan**

In 2011, Pakistan's largest province, Punjab, experienced an unprecedented dengue epidemic which infected over 21 000 citizens and resulted in 325 deaths. With the provincial health system in crisis mode, the authorities were rapidly overwhelmed, unable to track simultaneous interventions being undertaken by multiple departments, let alone predict locations where dengue larvae might appear.

At this point, the Punjab Information Technology Board stepped in. A team led by Professor Umar Saif, a former academic from the University of Cambridge (UK) and Massachusetts Institute of Technology (USA), designed a smartphone application to track the epidemic.

The application was pre-installed on 15 000 low-cost Android phones for as many government officials, who were required to upload before and after photographs of all their anti-dengue interventions. The entire data set was then geo-coded and displayed on a Google Maps-based dashboard, freely accessible to the public via internet and to senior government officials through smartphones. Teams of surveyors were despatched throughout the Lahore district, the provincial capital with the most dengue cases, to geo-code high-risk locations with dengue larvae, particularly around the homes of dengue-infected patients. The steady stream of geospatial data was then entered into a predictive algorithm to become an epidemic early warning system accessible to policy-makers at the highest level of government.

The project enabled the authorities to control the spread of the disease. The number of confirmed cases fell to 234 in 2012, none of which were fatal.

Source: High (2014); Rojahn (2012)

Table 21.4: **Researchers (FTE) in Pakistan's public sector by employer, 2011 and 2013**

	Government	Women (%)	Higher education	Women (%)	Share of total researchers working in government (%)	Share of total researchers working in higher education (%)
2011	9 046	12.2	17 177	29.6	34.5	65.5
2013	8 183	9.0	22 061	39.5	27.1	72.9

Note: Data for Pakistan exclude the business enterprise sector. FTE refers to full-time equivalents.

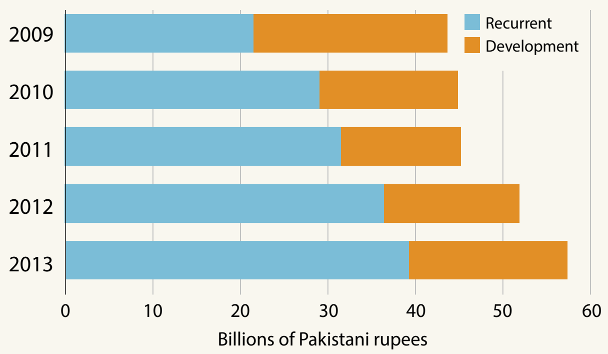
Source: UNESCO Institute for Statistics, June 2015

Decentralization of higher education governance

In 2002, the University Grants Commission was replaced with the Higher Education Commission (HEC), which has an independent chairperson. The HEC has been charged with reforming Pakistan's higher education system by introducing better financial incentives, increasing university enrolment and the number of PhD graduates, boosting foreign scholarships and research collaboration and providing all the major universities with state-of-the-art ICT facilities.

Between 2002 and 2009, the HEC succeeded in increasing the number of PhD graduates to 6 000 per year and in providing up to 11 000 scholarships for study abroad. It also introduced an e-library and videoconferencing facilities, according to the *UNESCO Science Report 2010*. The number of Pakistani publications recorded in the Web of Science leapt from 714 to 3 614 over the same period. The range of achievements during the reform period remains unprecedented in the history of Pakistan's higher education and R&D sectors. Moreover, publications in the Web of Science have since pursued their progression (Figure 21.8). This progress in scientific productivity appears to be due to the momentum generated by the larger numbers of faculty (Table 21.4) and student scholarships for study abroad, as well as the swelling ranks of PhD graduates.

Figure 21.12: **Pakistani Higher Education Commission's budgetary allocations, 2009–2014**



Source: Higher Education Commission of Pakistan

Despite these dramatic quantitative improvements across a variety of indicators, critics argue that this so-called 'numbers game' has compromised quality, a claim supported by the stagnation of Pakistani universities in global education rankings (Hoodbhoy, 2009).

Irrespective of this disagreement, the HEC found itself on the brink of dissolution in 2011–2012 in the face of the 18th amendment to the Constitution, which devolved several governance functions to provincial governments, including that of higher education. It was only after the Supreme Court intervened in April 2011, in response to a petition from the former Chair of the HEC, that the commission was spared from being divided up among the four Provinces of Baluchistan, Khyber–Pakhtunkhwa, Punjab and Sindh.

Notwithstanding this, the HEC's developmental budget – that spent on scholarships and faculty training, etc. – was slashed by 37.8% in 2011–2012, from a peak of R. 22.5 billion (*circa* US$ 0.22 billion) in 2009–2010 to Rs 14 billion (*circa* US$ 0.14 billion). The higher education sector continues to face an uncertain future, despite the marginal increase in developmental spending wrought by the new administration in Islamabad: Rs. 18.5 billion (*circa* US$ 0.18 billion) in the 2013–2014 budget.

In defiance of the Supreme Court ruling of April 2011, the provincial assembly of Sindh Province passed the unprecedented Sindh Higher Commission Act in 2013 creating Pakistan's first provincial higher education commission. In October 2014, Punjab Province followed suit as part of a massive restructuring of its own higher education system.

In sum, Pakistan's higher education sector is in transition, albeit with legal complications, towards a devolved system of governance undertaken at the provincial level. Although is too early to assess the potential impact of these developments, it is clear that the momentum of growth in spending and graduates in the higher education sector during the first decade of the century has now been lost. According to HEC statistics, the organization's budget as a percentage of national GDP has consistently fallen from the 2006-2007 peak of 0.33% to 0.19% in 2011–2012. In the interests of *Vision 2025*'s stated goal of building a knowledge economy, Pakistan's public policy apparatus will need to undertake a fundamental reprioritization of development spending, such as by giving itself the means to reach the target of devoting 1% of GDP to higher education.

Despite the turbulence caused by the legal battle being waged since the 2011 constitutional amendment discussed earlier, the number of degree-awarding institutions continues to grow throughout the country, both in the private and public sectors. Student rolls has been rising in tandem, from only 0.28 million in 2001 to 0.47 million in 2005, before crossing the 1.2 million mark in 2014. Just under half of universities are privately owned (Figure 21.13).

STI mainstreamed into development

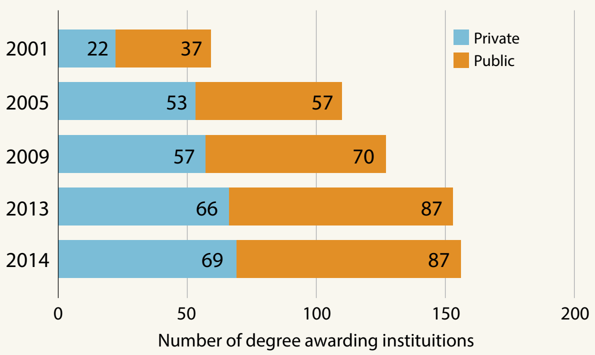
The overall picture of the STI sector in Pakistan is at best a mixed one. While the higher education sector faces an uncertain future, the government's mainstreaming of STI thinking into the national development narrative could signal a turnaround. Although indicators clearly show growth in higher education, they do not necessarily imply that the quality of education and research has also improved.

Moreover, the growth in PhD graduates and scientific publications does not appear to be having a discernible impact on innovation, as measured by patent activity. According to the World Intellectual Property Rights Organization (WIPO), patent applications[10] from Pakistan increased from 58 to 96 between 2001 and 2012 but the proportion of successful applications over the same period fell from 20.7% to 13.5%. This poor performance indicates a lack of a meaningful relationship between the university reforms and their impact on industry (Lundvall, 2009). As discussed above, the public sector continues to play a dominant role in the STI market, whereas the private sector appears to be lagging (Auerswald *et al*., 2012). This is also indicative of the non-existence of an appropriate entrepreneurial avenue (or culture), which is affecting Pakistan's global economic competitiveness.

Despite the mainstreaming of the national STI policy within national development policy, its potential impact on programmatic interventions remains far from clear. In order to achieve its goal of becoming a knowledge economy, Pakistan still requires a bolder vision from decision-makers at all levels of government.

10. These statistics are based on data collected from IP offices or extracted from the PATSTAT database. Source: www.wipo.int

Figure 21.13: **Growth in number of Pakistani universities, 2001–2014**



Source: Higher Education Commission of Pakistan

SRI LANKA

Strong growth since conflict's end

Mahinda Chintana: Vision for the Future 2020 (2010) is the overarching policy setting Sri Lanka's development goals to 2020; it aims to turn Sri Lanka into a knowledge economy and one of South Asia's knowledge hubs. The newfound political stability since the end of the prolonged civil war in 2009 has spawned a building boom since 2010, with the government investing in strategic development projects to build or expand motorways, airports, seaports, clean coal plants and hydropower. These projects are designed to turn Sri Lanka into a commercial hub, naval/maritime hub, aviation hub, energy hub and tourism hub. The Strategic Investment Projects Act of 2008 (amended in 2011 and 2013) was introduced to provide a tax-free period for the implementation of strategic development projects.

In order to attract FDI and technology transfer, the government has signed a series of agreements with foreign governments, including those of China, Thailand and the Russian Federation. Within an agreement signed in 2013, for instance, the Russian State Atomic Energy Corporation (ROSATOM) is assisting Sri Lanka's Atomic Energy Authority in developing nuclear energy infrastructure and a nuclear research centre, as well as providing training for workers. In 2014, the government signed an agreement with China for the expansion of the Port of Colombo and the development of infrastructure (port, airport and motorway) in Hambantota, which the government plans to turn into Sri Lanka's second urban hub after the capital. The agreement with China also covers technical co-operation on the Norochcholai Coal Power Project.

Between 2010 and 2013, GDP increased by 7.5% per year on average, up from 3.5% in 2009. In parallel, GDP per capita grew by 60% from US$2 057 to US$ 3 280 between 2009 and 2013. Although Sri Lanka's rank in the knowledge economy index dropped from 4.25 to 3.63 between 1999 and 2012, it remains higher than for all other South Asian countries.

Sri Lanka has made the transition from an agricultural economy to one based on services and industry (Figure 21.10) but the proportionate supply of science and engineering graduates from local universities is lower than for other disciplines.

Higher education reforms seek to expand capacity

Sri Lanka is likely to achieve universal primary education and gender parity by 2015, according to UNESCO's *Education for All Global Monitoring Report* (2015). One concern is the low level of public spending on education, which even dropped between 2009 and 2012 from 2.1% to 1.7% of GDP, the lowest level in South Asia (Figure 21.3).

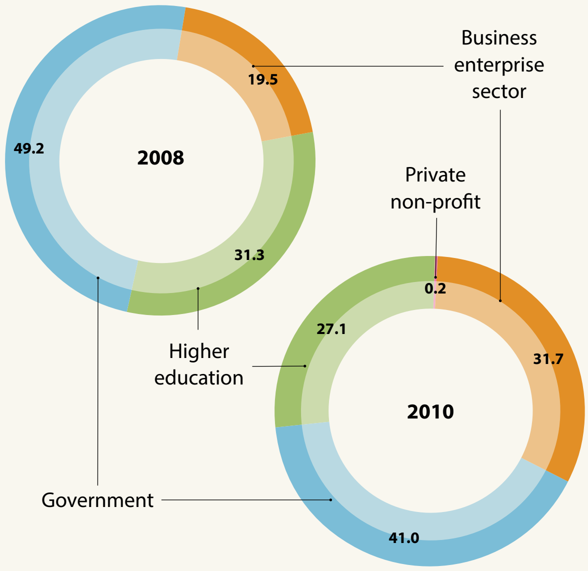
Sri Lanka counts 15 state-controlled universities which operate under the University Grants Commission (UGC) and a further three under the Ministries of Defence, Higher Education and Vocational and Technical Training. These 18 state universities are complemented by 16 registered private universities offering bachelor's or master's degrees.

At 0.3% of GDP, Sri Lanka's public spending on higher education is one of the lowest in South Asia, on a par with that of Bangladesh. According to the UGC, only 16.7% of the students who qualified for university could be admitted for the year 2012–2013. These factors explain the relatively low proportion of researchers in Sri Lanka – a head count of just 249 per million inhabitants in 2010 – , and the modest progress in recent years (Figure 21.7). Of note is that the share of researchers working in the business enterprise sector (32% in full-time equivalents for 2010) is approaching that of India (39% in 2010), a trend which augurs well for the development of a dynamic private sector in Sri Lanka (Figure 21.14). In 2012, the Sri Lankan government announced tax incentives for private companies undertaking R&D and for the use of public research facilities.

The government has spent the past few years addressing the insufficient number of university places. This is one of the objectives of the Higher Education for the Twenty-first Century Project (2010–2016), which aims to ensure that universities are in a position to deliver quality services aligned with the country's socio-economic needs. The mid-term review in 2014 identified the following achievements:

- progressive implementation of the Sri Lanka Qualification Framework (SLQF, est 2012) by national institutes and universities; it regulates the ten levels of qualification offered by public and private post-secondary institutions to enhance equity in higher education, training and job opportunities and facilitate lateral and vertical mobility in the university system; the SLQF integrates the National Vocational Qualification Framework (2005) and identifies pathways for ensuring mobility between vocational and higher education by providing a nationally consistent basis for recognizing prior learning and the transfer of credits;

Figure 21.14: **Sri Lankan researchers (FTE) by sector of employment, 2008 and 2010**



Source: UNESCO Institute for Statistics, June 2015

- implementation of University Development Grants to improve the skills of students at all universities in relation to information technology (IT), English and soft skills, such as conscientiousness or leadership qualities, which are valued by employers at all target 17 universities;
- implementation of Innovatory Development Grants for university students enrolled in the arts, humanities and social sciences at all target 17 universities;
- award of Quality and Innovation Grants (QIG), which enhance the quality of academic teaching, research and innovation, to 58 study programmes, exceeding the project target of 51; nearly all QIGs are performing well;
- enrolment of over 15 000 students in advanced technological institutions, surpassing the current project target of 11 000;
- commencement of master's or PhD degree programmes by over 200 academics from universities and the Sri Lanka Institute of Advanced Technological Education, exceeding the project target of 100 master's/PhD degrees; and
- about 3 560 beneficiaries of short-term professional development activities targeting university administrators and managers, academics and technical and support staff.

Greater mobility for Sri Lankan engineers

In June 2014, the premier body for engineers in Sri Lanka, the Institution of Engineers, became a signatory of the Washington Accord, along with its Indian counterpart. The Washington Accord is an international agreement by which bodies responsible for accrediting engineering degree programmes recognize the graduates of other signatory bodies as having met the academic requirements for entry into the engineering profession. This recognition offers future Sri Lankan and Indian engineers easy mobility throughout the signatory countries.[11]

Sri Lanka's first STI policy

Sri Lanka's first comprehensive *National Science and Technology Policy* was adopted in June 2009, following a thorough consultative process with all stakeholders, as outlined in the *UNESCO Science Report 2010*. These consultations identified the need to develop a science and innovation culture, build human resource capabilities and promote R&D and technology transfer. Participants also felt that the policy should foster sustainability and indigenous knowledge, propose a defined system of intellectual property rights and promote the application of science and technology for human welfare, disaster management, adaptation to climate change, law enforcement and defence.

Under the objective of 'Enhancing Science and Technology Capability for National Development', the policy identifies strategies for increasing ' the state sector investment in science and technology to 1% of GDP by 2016 and facilitating the non-state sector investment in R&D to at least 0.5% of the GDP by 2016.' This is an ambitious target, since the government devoted just 0.09% of GDP to GERD in 2010 and the business enterprise sector (public and private) a further 0.07%.

Approved by the Cabinet in 2010, the *National Science, Technology and Innovation Strategy* (2011–2015) serves as the roadmap for implementing the *National Science and Technology P*olicy. The body responsible for piloting the strategy, the Co-ordinating Secretariat for Science, Technology and Innovation (COSTI), was set up for this purpose in 2013. COSTI is currently preparing an evaluation of the national research and innovation ecosystem.

The *National Science, Technology and Innovation Strategy* (2011–2015) identifies four broad goals:

- Harness innovation and technology to economic development through focused R&D and dynamic technology transfer to increase the share of high-tech products for export and the domestic market; the main target of the Advanced Technology Initiative is to raise the share of high-tech products among exports from 1.5% in 2010 to 10% by 2015;
- Develop a world-class national research and innovation ecosystem;
- Establish an effective framework to prepare the population of Sri Lanka for a knowledge society; and
- Ensure that the sustainability principle is entrenched in all spheres of scientific activity to ensure socio-economic and environmental sustainability.

A better quality of life through R&D

Adopted in July 2014, the *National Investment Framework for Research and Development for 2015–2020* identifies ten focus areas for investment in R&D to improve the quality of life. Relevant government ministries and other public and private institutions were asked to take part in the study, in order to recommend national R&D priorities.

The ten focus areas are:

- Water;
- Food, nutrition and agriculture;
- Health;
- Shelter;
- Energy;
- Textile industry;
- Environment;
- Mineral resources;
- Software industry and knowledge services;
- Basic sciences, emerging technologies and indigenous knowledge.

Nanotechnology a priority

Development of the industrial sector has accelerated since the Cabinet approved[12] the *National Biotechnology Policy* in 2010 and the *National Nanotechnology Policy* in 2012.

Nanotechnology got its first institutional boost in 2006 with the launch of the National Nanotechnology Initiative. Two years later, the government established the Sri Lanka Institute of Nanotechnology (SLINTEC) in an unprecedented joint venture with the private sector (Box 21.7). In 2013, the Nanotechnology and Science Park opened, along with the Nanotechnology Centre of Excellence, which provides high quality infrastructure for nanotechnology research. In 2013, Sri Lanka ranked 83rd for the number of nano-articles in the Web of Science per million inhabitants (Figure 21.8). It trails Pakistan (74th), India (65th) and Iran (27th) for this indicator (for India and Iran, see Figure 15.5).

11. Among the other signatories are Australia, Canada, Ireland, Japan, Rep. Korea, Malaysia, New Zealand, Russia, Singapore, South Africa, Turkey, the UK and USA. See: www.iesl.lk

12. A third sectorial policy on human genetic material and data was still in draft form at the time of writing in mid-2015.

Box 21.7: Developing smart industry through the Sri Lanka Institute of Nanotechnology

The Sri Lanka Institute of Nanotechnology (SLINTEC) was established in 2008 as in a joint venture between the National Science Foundation and Sri Lankan corporate giants that include Brandix, Dialog, Hayleys and Loadstar. Its aims are to:

- build a national innovation platform for technology-based economic development by helping to raise the proportion of high-tech exports from 1.5% to 10% of total exports by 2015 and through the commercialization of nanotechnology;
- deepen collaboration between research institutes and universities;
- introduce nano-aspects of leading technologies and industries to make Sri Lankan products more competitive globally and add value to Sri Lanka's natural resources;
- bring nanotechnology research and business enterprises together; and
- attract expatriate Sri Lankan scientists by creating a sustainable ecosystem.

Less than one year after its inception, SLINTEC filed five international patents with the United States Patent and Trademark Office, a remarkable achievement. Two additional patent applications were filed in 2011 and 2012. These inventions include a process for the preparation of carbon nanotubes from vein graphite; compositions for sustained release of agricultural macronutrients and related processes; a cellulose-based sustained release macronutrient composition for fertilizer application; a process for reinforcing elastomer-clay nano-composites; a process for preparing nanoparticles from magnetite ore; a nanotechnology-based sensor unit; a composition for stain and odour removal from bio-polymeric fabrics, etc.

Gunawardena (2012) identified the focus areas of SLINTEC as:

- *Smart agriculture:* nanotechnology-based slow release fertilizer; potential expansion to sensors and next generation fertilizers;
- *Rubber nano-composites:* high-performance tyres;
- *Apparel and textile:* high-end fabrics, smart yarns and other technologies;
- *Consumer products:* a nanotechnology-based external medical sensor with a view to enabling remote health monitoring, detergents, cosmetics, etc.;
- *Nano-materials:* ilmenite, clay, magnetite, vein quartz and vein graphite to develop titanium dioxide, montmorillonite, nanomagnetite, nanosilica and graphite nanoplatelets.

Source: http://slintec.lk

Schemes to foster innovation

The National Science Foundation has instituted two technology grant schemes to encourage innovation. The first (Tech D) helps universities, research institutes, private firms and individuals develop their ideas, whereas the second focuses on start-ups based on novel technologies. In 2011, five Tech D grants and one start-up grant were awarded.

In 2013, the Ministry of Technology and Research organized its third Technology Marketplace exhibition to provide a forum where scientific research and industry could meet. The ministry has directed its five research bodies to focus on demand-driven research: the Industrial Technology Institute, National Engineering Research and Development Centre, Atomic Energy Board, SLINTEC and the Arthur C. Clarke Institute for Modern Technologies.

In 2010, the USA-based Blue Ocean Ventures launched the Lankan Angels Network. By 2014, the investors operating within this network had injected US$1.5 million into 12 innovative Sri Lankan companies, within a partnership with the Sri Lankan Inventors Commission (est. 1979). The Ministry of Technology and Research reported in 2013 that the Commission had disbursed just LKR 2.94 million (*circa* US$ 22 000) in grants through its own Inventor's Fund the same year.

Smart people, smart island

The first framework for generalizing ICTs was the e-Sri Lanka roadmap launched in 2002, which spawned the Information and Communication Technology Act and the founding of the government-owned Information and Communication Technology Agency (ICTA) in 2003. ICTA implemented the government's e-Sri Lanka Development Project, which sought to bring ICTs to every village, until the project's end in 2013. By 2013, 22% of the population had access to internet, compared to just 6% in 2008, and 96% had a mobile phone subscription.

Phase 2 of the e-Sri Lanka Development Project was launched by ICTA in 2014, in order to spur economic development through innovation in ICTs. Known as Smart Sri Lanka, the project is expected to run for about six years. Its slogan is 'smart people, smart island.' Its goals could be summed up as: smart leadership, smart government, smart cities, smart jobs, smart industries and a smart information society.

Smart Sri Lanka reposes on six programmatic strategies to achieve its goal:

- ICT policy, leadership and institutional development;
- Information infrastructure;
- Re-engineering government;
- ICT human resource development;
- ICT investment and private sector development; and
- The e-society.

In parallel, ICTA has set up telecentres *(nenasalas)* across the country, in order to connect communities of farmers, students and small entrepreneurs to information, learning and trading facilities. These telecentres provide people with access to computers, internet and training in IT skills. The *nenasalas* also provide access to local radio broadcasts of market prices and agricultural information for farmers; e-health and telemedecine facilities for rural patients; and digital 'talking books' (audio books) for the visually impaired. Three types of *nenasala* have been implemented: rural knowledge centres; e-libraries; and distance and e-learning centres. As of August 2014, there were 800 *nenasalas* across the country.[13]

CONCLUSION

A need to blend local and external capacity

There have been some significant improvements in education since 2010 in South Asia, along with more modest progress in developing national innovation systems. In both areas, low levels of public funding have been an obstacle to development but, in the case of education, government efforts have been supplemented by projects funded by international donor agencies. Despite gains in net primary school enrolment, uptake to secondary-level education enrolment nevertheless remains relatively low: the most populous countries, Bangladesh and Pakistan, have reported levels of only 61% (2013) and 36% (2012) respectively.

Universal primary and secondary education is only the first step towards developing the requisite professional and technical skills that countries will need to realize their ambition of becoming a knowledge economy (Pakistan and Sri Lanka) or middle-income country (Bangladesh, Bhutan and Nepal) within the next decade. Building an educated labour force will be a prerequisite for developing the high-value-added industries needed to undertake the desired industrial diversification. Education planning will need to include investment in infrastructure, programmes to improve teaching skills and the development of curricula that match skills with employment opportunities.

13. See: www.nenasala.lk

In order to exploit a broad spectrum of opportunities, national innovation systems should be designed to enable both the development of local capacity in research and innovation and the acquisition of external knowledge and technologies which can generally be found in locally operated, technologically advanced firms. Whereas the majority of industries in South Asia are not yet technologically advanced, there are nevertheless a few local firms that have become internationally competitive, particularly in Pakistan and Sri Lanka. Given the heterogeneity among firms in terms of their technological innovativeness, the national innovation system will need to be sufficiently flexible to support their different technological requirements. Whereas local innovation systems are usually designed to support R&D-led innovation, countries that are able to capitalize systemically on the accumulated capabilities of high-performing local firms and implanted multinationals to nurture their industries are likely to generate broader innovative capabilities.

Economic development through FDI requires a high level of local responsiveness and absorptive capacity, in particular with regard to technology diffusion. The FDI inflows to the South Asian economies reviewed in the present chapter have not significantly contributed to their growth, in comparison with countries in East Asia. Technologically advanced economic sectors where value chain activities are able to utilize existing local knowledge, skills and capabilities have an opportunity to upgrade their local industries.

Governments need to ensure that sufficient funds are available for the implementation of national research and education policies. Without adequate resources, it is unlikely that these policies will bring about effective change. Governments are aware of this. Pakistan has set targets to increase its investment in R&D to 1% of GDP by 2018 and Sri Lanka plans to increase its own investment to 1.5% of GDP by 2016, with a public sector contribution of at least 1%. These targets look good on paper but have governments put in place the mechanisms to reach them? Spending on R&D also has to be prioritized, if limited financial and human resources are to make the desired impact.

Public–private partnerships can be an important ally in policy implementation – as long as the private sector is sufficiently robust to shoulder part of the burden. If not, tax incentives and other business-friendly measures can give the private sector the boost it needs to become an engine of economic development. Public–private partnerships can create synergies between firms, public R&D institutes and universities for industry-led innovation, one obvious example in this respect being SLINTEC (Box 21.7).

The lack of infrastructural capacity to support the use of internet remains a challenge for many South Asian countries. This leaves them unable to connect their own internal urban and rural economies or with the rest of the world. All countries have made efforts to include ICTs in education but the availability and quality of the electricity supply in rural areas and the deployment of ICTs are still major concerns. Mobile phone technology is widespread, being used by farmers, school children, teachers and businesses; this almost ubiquitous, easily accessible and affordable technology represents an enormous but still underutilized opportunity for information- and knowledge-sharing, as well as for the development of commercial and financial services across urban and rural economies.

KEY TARGETS FOR SOUTH ASIAN COUNTRIES

- Raise the share of higher education to 20% of the Afghan education budget by 2015;
- Ensure that women represent 30% of Afghan students and 20% of faculty by 2015;
- Raise the contribution of industry to 40% of GDP in Bangladesh and increase the share of workers employed by industry to 25% of the labour force by 2021;
- Reduce the share of workers employed in agriculture in Bangladesh from 48% of the labour force in 2010 to 30% in 2021;
- Create a National Council for Research and Innovation in Bhutan;
- Broaden access to higher education in Pakistan from 7% to 12% of the age cohort and increase the number of new PhDs per year from 7 000 to 25 000 by 2025;
- Raise Pakistan's GERD to 0.5% of GDP by 2015 and to 1% of GDP by 2018;
- Increase expenditure on higher education to at least 1% of GDP in Pakistan by 2018;
- Raise Sri Lanka's GERD from 0.16% of GDP in 2010 to 1.5% of GDP by 2016, to which the private sector should contribute 0.5% of GDP, compared to 0.07% in 2010;
- Augment the share of Sri Lankan high-tech products from 1.5% (2010) to 10% of exports by 2015.

REFERENCES

ADB (2014) *Innovative Strategies in Technical and Vocational Education and Training*. Asian Development Bank.

ADB (2013) *Nepal Partnership Strategy 2013–2017*. Asian Development Bank.

Amjad, R. and Musleh U. Din (2010) *Economic and Social impact of the Global Financial Crisis: Implications for Macroeconomic and Development Policies in South Asia.* Munich Personal RePEc Archive Paper.

ADB (2012) *Completion Report – Maldives: Employment Skills Training Project*. Asian Development Bank: Manila.

Auerswald, P.; Bayrasli, E. and S. Shroff (2012) Creating a place for the future: strategies for entrepreneurship-led development in Pakistan. *Innovations: Technology, Governance, Globalization,* 7 (2): 107–34.

Clover, Ian (2015) Pakistan overhauls its solar industry for the better. *PV Magazine*. See: www.pv-magazine.com

Gopalan, S.; Malik, A. A. and K. A. Reinert (2013) The imperfect substitutes model in South Asia: Pakistan–India trade liberalization in the negative list. *South Asia Economic Journal*, 14(2): 211–230.

Government of Nepal (2013a) Briefing on the Establishment of a Technology Research Centre in Nepal. Singha Durbar, Kathmandu. See: http://moste.gov.np.

Government of Nepal (2013b) An Approach Paper to the Thirteenth Plan (FY 2013/14 – 2015/16). National Planning Commission, Singha Durbar, Kathmandu, July.

Gunawardena, A. (2012) *Investing in Nanotechnology in Sri Lanka*. Sri Lanka Institute of Nanotechnology (SLINTEC): Colombo.

High, P. (2014) A professor with a Western past remakes Pakistan's entrepreneurial Future. *Forbes*.

Hoodbhoy, P. (2009) Pakistan's Higher Education System – What Went Wrong and How to Fix It. *The Pakistan Development Review*, pp. 581–594.

Hossain, M. D. *et al*. (2012) Mapping the dynamics of the knowledge base of innovations of R&D in Bangladesh: a triple helix perspective. *Scientometrics* 90.1 (2012): 57–83.

Khan, S. R.; Shaheen, F. H., Yusuf, M. and A. Tanveer (2007) Regional Integration, Trade and Conflict in South Asia. Working Paper. Sustainable Development Policy Institute: Islamabad.

Lundvall, B.-A (2009) Innovation as an Interactive Process : User–Producer Interaction in the National System of Innovation. Research Paper. See: http://reference.sabinet.co.za

MoE (2014) *Annual Education Statistics 2014*. Ministry of Education of Bhutan: Thimphu.

MoHE (2013) *Higher Education Review for 2012: an Update on the Current State of Implementation of the National Higher Education Strategic Plan: 2010–2014*. Government of Afghanistan: Kabul.

MoHE (2012) *Sri Lanka Qualifications Framework*. Ministry of Higher Education of Sri Lanka: Colombo.

MoTR (2011) *Science, Technology and Innovation Strategy*. Ministry of Technology and Research of Sri Lanka: Colombo.

MoLHR (2013) *11th National Labour Force Survey Report 2013*. Department of Employment, Ministry of Labour and Human Resources of Bhutan: Thimpu.

NAST (2010) *Capacity Building and Management of Science, Technology and Innovation Policies in Nepal. Final Report*. Prepared for UNESCO by Nepal Academy of Science and Technology.

Planning Commission (2014) *Pakistan Vision 2025*. Ministry of Planning, Development and Reform of Bangladesh: Islamabad. See: http://pakistan2025.org.

Planning Commission (2012) Perspective Plan of Bangladesh, 2010 –2021. Final Draft, April. Government of Bangladesh: Dhaka.

Republic of Maldives (2007a) *Maldives Climate Change In-Depth Technology Needs Assessment – Energy Sector.* Study conducted by the Commerce Development and Environment Pvt Ltd for the Ministry of Environment, Energy and Water, July.

Republic of Maldives (2007b) *In-Depth Technology Needs Assessment – Transport Sector.* Study conducted by Ahmed Adham Abdulla, Commerce Development and Environment Pvt Ltd for the Ministry of Environment, Energy and Water, September.

Saez, Lawrence (2012) *The South Asian Association for Regional Cooperation (SAARC): An Emerging Collaboration Architecture*. Routledge Publishers.

Rojahn, S.Y. (2012) Tracking dengue fever by smartphone and predicting outbreaks online. *MIT Technology Review*: Massachusetts, USA.

UNDP (2014) *Human Development Report 2014 – Sustaining Human Progress: Reducing Vulnerabilities and Building Resilience*. United Nations Development Programme: New York.

UIS (2014a) *Higher Education in Asia: Expanding Out, Expanding Up. The Rise of Graduate Education and University Research*. UNESCO Institute for Statistics: Montreal.

UIS (2014b) *Information and Communication Technology in Education in Asia - a Comparative Analysis of ICT Integration and E-readiness in Schools across Asia*. UNESCO Institute for Statistics: Montreal.

Valk, J.-H.; Rashid, A. T. and L. Elder (2010). Using Mobile Phones to Improve Educational Outcomes: an Analysis of Evidence from Asia. *The International Review of Research in Open and Distance Learning,* 11: 117–140.

Van Alphen, K. *et al.* (2008) Renewable energy technologies in the Maldives: realizing the potential. *Renewable and Sustainable Energy Reviews* 12, 162–180.

World Bank (2014) *Regional Integration in South Asia*. Brief. World Bank: Washington, D.C.

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The government needs to support the emergence of technology-based start-ups to broaden the innovation culture in India.

Sunil Mani

The majority of pharmaceutical patents are owned by Indian firms, whereas foreign firms established in India tend to own the majority of patents in computer software.
Photo © A and N photography/Shutterstock.com

22 · India

Sunil Mani

INTRODUCTION

Jobless growth: an emerging concern

For the first time in its history, India's economy grew at around 9% per annum between 2005 and 2007. Ever since, GDP has been progressing at a much slower pace of around 5%, primarily as a corollary of the global financial crisis in 2008, even though it did bounce back briefly between 2009 and 2011 (Table 22.1).

India has experienced mixed fortunes in recent years. On the positive side, one could cite the systematic reduction in poverty rates, improvements in the macro-economic fundamentals that nurture economic growth, a greater flow of both inward and outward foreign direct investment (FDI), the emergence of India since 2005 as the world leader for exports of computer and information services and the country's evolution into a hub for what are known as 'frugal innovations', some of which have been exported to the West. On the down side, there is evidence of growing inequality in income distribution, a high inflation rate and current deficit, as well as sluggish job creation despite economic growth, a phenomenon that goes by the euphemism of 'jobless growth'. As we shall see, public policy has strived to reduce the deleterious effects of these negative features without imperilling the positive ones.

Come manufacture in India!

In May 2014, the Bharatiya Janata Party became the first party in 30 years to win a majority of parliamentary seats (52%) in the general elections, allowing it to govern without the support of other parties. Prime Minister Narendra Modi will thus have considerable freedom in implementing his programme between now and the next general elections in 2019.

In his speech delivered on Independence Day on 15 August 2014, the prime minister argued for a new economic model based on export-oriented manufacturing. He encouraged both domestic and foreign companies to manufacture goods for export in India, proclaiming several times, 'Come manufacture in India!' Today, India's economy is dominated by the services sector, which represents 57% of GDP, compared to 25% for industry, half of which comes from manufacturing[1] (13% of GDP in 2013).

The new government's shift towards an East Asian growth[2] model with a focus on the development of manufacturing and heavy infrastructure is also driven by demographic trends: 10 million young Indians are joining the job market each year and many rural Indians are migrating to urban areas. The services sector may have fuelled growth in recent

1. The *National Manufacturing Policy* (2011) advocated raising the share of manufacturing from 15% to about 25% of GDP by 2022. The policy also proposed raising the share of high-tech products (aerospace, pharmaceuticals, chemicals, electronics and telecommunications) among manufactured products from 1% to at least 5% by 2022 and augmenting the current share of high-tech goods (7%) among manufactured exports by 2022.

2. The East Asian growth model implies a strong role for the state in raising the domestic investment rate as a whole and specifically in manufacturing industries.

Table 22.1: **Positive and disquieting features of India's socio-economic performance, 2006–2013**

	2006	2008	2010	2012	2013
Rate of real GDP growth (%)	9.3	3.9	10.3	4.7	4.7
Savings rate (% of GDP)	33.5	36.8	33.7	31.3	30.1
Investment rate (% of GDP)	34.7	38.1	36.5	35.5	34.8
Population living below poverty line (%)	37.20^{-1}	–	–	21.9	–
Population without access to improved sanitation (%)	–	–	–	64.9^{-1}	–
Population without access to electricity (%)	–	–	–	24.7^{-1}	–
Inward net FDI inflow (US$ billions)	8.90	34.72	33.11	32.96	30.76^{+1}
Outward net FDI outflow (US$ billions)	5.87	18.84	15.14	11.10	9.20^{+1}
India's world share of exports of computer software services (%)	15.4	17.1	17.5	18.1	–
Inflation, consumer prices (%)	6.15	8.35	11.99	9.31	10.91
Income inequality (Gini index)	33.4		35.7	–	–
Jobless growth (growth ratio of employees in organized sector)	0.20	0.12	0.22	–	–

+n/-n: data refer to *n* years before or after reference year

Source: Central Statistical Organization; Reserve Bank of India; UNDP (2014); World Water Assessment Programme (2014) *World Water Development Report: Water and Energy* years but it has not created mass employment: only about one-quarter of Indians work[3] in this sector. One challenge will be for the government to create a more business-friendly fiscal and regulatory environment. India will also need to raise its fixed investment ratio well above the current 30%, if it is to emulate the success of the East Asian model (Sanyal, 2014).

In his speech, Modi also announced the disbanding of the nation's Planning Commission. This represents one of the most significant policy shifts in India since the release of the *UNESCO Science Report 2010*. This decision has effectively sounded a death knell to the planned form of development pursued by India over the past six and a half decades, which has resulted in a long series of medium-term development plans with explicit targets. On 1 January 2015, the government announced that the Planning Commission would be replaced by the National Institution for Transforming India (NITI Ayog). The role of this new think tank on development issues will be to produce reports on strategic issues for discussion by the National Development Council, in which all the chief ministers participate. In a departure from past practice, NITI Ayog will accord India's 29 states a much greater role in policy formulation and implementation than the erstwhile Planning Commission. The new think tank will also play an active role in implementing schemes sponsored by the central government.

Despite this development, the *Twelfth Five-Year Plan* (2012–2017) will still run its course. Up until now, the Planning Commission has co-ordinated India's wide spectrum of institutions supporting technological change, essentially through these five-year plans. These institutions include the Scientific Advisory Council to the Prime Minister, the National Innovation Council and the Ministry of Science and Technology. The new think tank will take over this co-ordination role.

In 2014, the new government made two proposals with regard to science. The first was for India to adopt a comprehensive policy on patents. The second was for senior researchers from government laboratories to work as science teachers in schools, colleges and universities as a way of improving the quality of science education. A committee of experts was subsequently appointed to draw up the policy on patents. However, the draft report submitted by the committee in December 2014 does not call for an overhaul of the existing policy. Rather, it encourages the government to popularize a patent culture among potential inventors from both the formal and informal economic sectors. It also recommends that India adopt utility models in its patent regime, in order to incite small and medium-sized enterprises (SMEs) to be more innovative.

3. The low level of job creation may be explained by the fact that the services sector is dominated by retail and wholesale trade (23%), followed by real estate, public administration and defence (about 12% each) and construction services (about 11%). See Mukherjee (2013).

India's foreign policy will not break with the past

The Modi government's foreign policy is unlikely to depart from that of previous governments which have considered, in the words of India's first prime minister, Jawaharlal Nehru, that 'ultimately, foreign policy is the outcome of economic policy.' In 2012–2013, India's three biggest export markets were the United Arab Emirates, USA and China. It is noteworthy, however, that Narendra Modi is the first Indian prime minister to have invited all the heads of government of the South Asian Association for Regional Cooperation (SAARC)[4] to his swearing-in ceremony on 26 May 2014. All accepted the invitation. Moreover, at the November 2014 SAARC summit, Prime Minister Modi appealed to SAARC members to give Indian companies greater investment opportunities in their countries, in return for better access to India's large consumer market (see p. 569).

When it comes to innovation, Western nations will no doubt remain India's primary trading partners, despite India's ties to the other BRICS countries (Brazil, Russia, China and South Africa), which resulted in the signing of an agreement in July 2014 to set up the New Development Bank (or BRICS Development Bank), with a primary focus on lending for infrastructure projects.[5]

Three factors explain India's continued reliance on Western science and technology (S&T). First among them is the growing presence of Western multinationals in India's industrial landscape. Secondly, a large number of Indian firms have acquired companies abroad; these tend to be in developed market economies. Thirdly, the flow of Indian students enrolling in science and engineering disciplines in Western universities has increased manifold in recent years and, as a result, academic exchanges between Indian and Western nations are very much on the rise.

Economic growth has driven dynamic output in R&D

All indicators of output from research and development (R&D) have progressed rapidly in the past five years, be they for patents granted nationally or abroad, India's share of high-tech exports in total exports or the number of scientific publications (Figure 22.1). India has continued building its capability in such high-tech industries as space technology, pharmaceuticals and computer and information technology (IT) services.

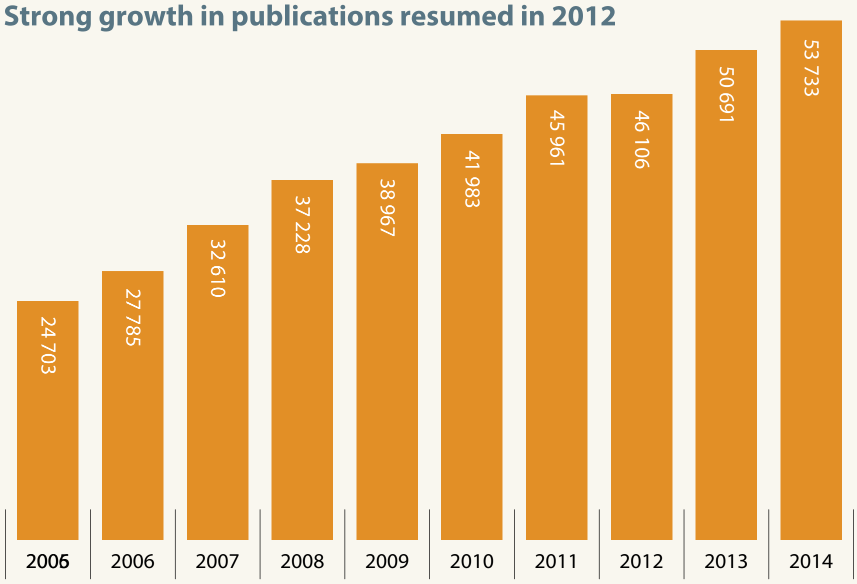
Two recent achievements illustrate the distance India has travelled in recent years: its position as world leader since 2005 for exports of computer and information services and

4. See Box 21.1 for details of the South Asian University, a SAARC project.

5. Each of the five BRICS contributes an equal financial share to the bank, which is to be endowed with initial capital of US$ 100 billion. The bank is headquartered in Shanghai (China), with India holding the presidency and a regional antenna in South Africa.

Figure 22.1: **Scientific publication trends in India, 2005–2014**

Strong growth in publications resumed in 2012



0.76

Average citation rate for Indian scientific publications, 2009–2012; the G20 average is 1.02

6.4%

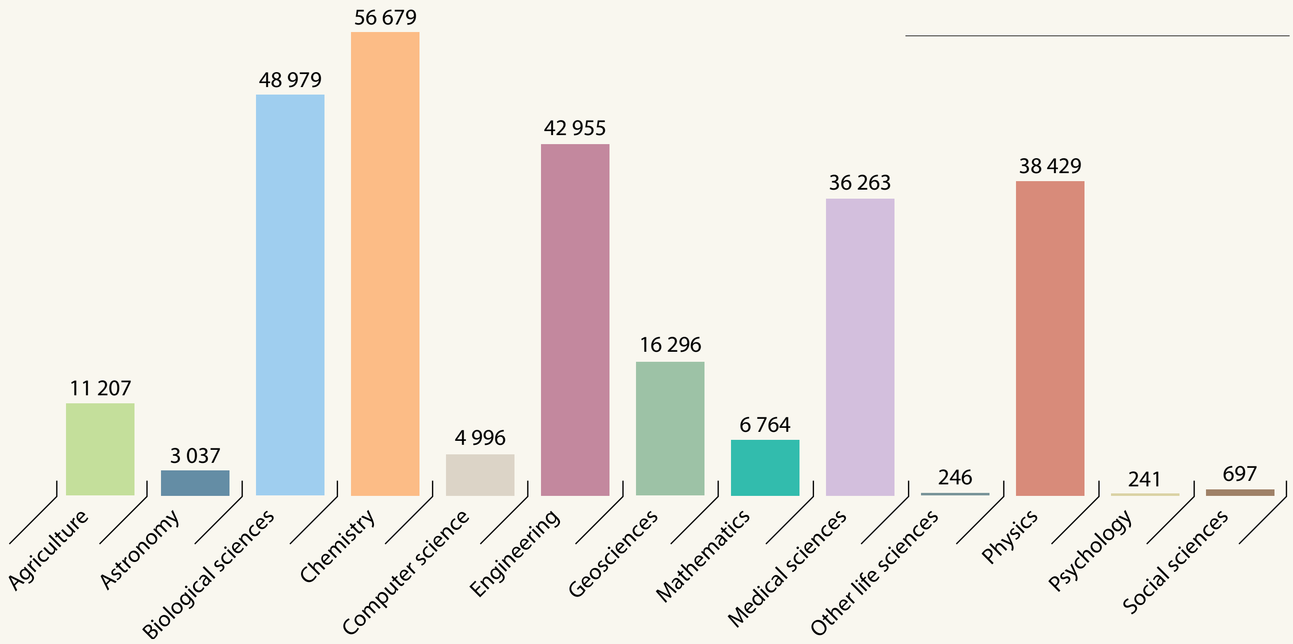
Share of Indian papers among 10% most cited papers, 2009–2012; the G20 average is 10.2%

21.3%

Share of Indian papers with foreign co-authors, 2008–2014; the G20 average is 24.6%

Indian scientific output is fairly diversified

Cumulative totals by field 2008–2014



The USA remains India's main scientific collaborator

Main foreign partners 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
India	USA (21 684)	Germany (8 540)	UK (7 847)	Korea, Rep. of (6 477)	France (5 859)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

the success of its maiden voyage to Mars[6] in September 2014, which carried frugal innovation to new heights: India had developed its Mangalyaan probe at a cost of just US$ 74 million, a fraction of the cost of the US$ 671 million Maven probe developed by the US National Aeronautics and Space Administration (NASA), which arrived in Mars' orbit just three days ahead of Mangalyaan. Until this feat, only the European Space Agency, USA and former Soviet Union had got as far as Mars' atmosphere; out of 41 previous attempts, 23 had failed, including missions by China and Japan.

India is also collaborating on some of the most sophisticated scientific projects in the world. India's Atomic Energy Commission participated in the construction of the world's largest and most powerful particle accelerator, the Large Hadron Collider (LHC), which came on stream in 2009 at the European Organization for Nuclear Research (CERN) in Switzerland; several Indian institutions are involved in a multiyear experiment[7] which uses the LHC. India is now participating in the construction of another particle accelerator in Germany, the Facility for Antiproton and Ion Research (FAIR), which will host scientists from about 50 countries from 2018 onwards. India is also contributing to the construction of the International Thermonuclear Experimental Reactor in France by 2018.

Indian science has nonetheless had its ups and downs and the country has historically given more importance to producing science than technology. As a result, Indian companies have had less success in manufacturing products which require engineering skills than in science-based industries like pharmaceuticals.

In recent years, the business enterprise sector has become increasingly dynamic. We shall begin by analysing this trend, which is rapidly reshaping the Indian landscape. The three biggest industries – pharmaceuticals, automotive and computer software – are all business-oriented. Even frugal innovation tends to be oriented towards products and services. Among government agencies, it is the defence industry which dominates R&D but, up until now, there has been little transfer of technology to civil society. That is about to change.

In order to sustain India's high-tech capacity, the government is investing in new areas such as aircraft design, nanotechnology and green energy sources. It is also using India's capabilities in information and communication technologies (ICTs) to narrow the urban–rural divide and setting up centres of excellence in agricultural sciences to reverse the worrying drop in yields of some staple food crops.

In recent years, industry has complained of severe shortages of skilled personnel, as we saw in the *UNESCO Science Report 2010*. University research has also been in decline. Today, universities perform just 4% of Indian R&D. The government has instigated a variety of schemes over the past decade to correct these imbalances. The latter part of this essay will be devoted to analysing how effective these schemes have been.

TRENDS IN INDUSTRIAL RESEARCH

Business R&D is growing but not R&D intensity overall

The only key indicator which has stagnated in recent years is the measure of India's R&D effort. Sustained economic growth pushed gross domestic expenditure on research and development (GERD) up from PPP$ 27 billion to PPP$ 48 billion between 2005 and 2011 but this growth of 8% per annum (in constant PPP$) was only sufficient to maintain the country's GERD/GDP ratio at the same level in 2011 as six years earlier: 0.81% of GDP.

India's Science and Technology Policy of 2003 has thus failed to realize its objective of carrying GERD to 2.0% of GDP by 2007. This has forced the government to set back its target date to 2018 in the latest *Science, Technology and Innovation Policy* (2013). China, on the other hand, is on track to meet its own target of raising GERD from 1.39% of GDP in 2006 to 2.50% by 2020. By 2013, China's GERD/GDP ratio stood at 2.08%.

The *Science and Technology Policies* of both 2003 and 2013[8] have emphasized the importance of private investment to develop India's technological capability. The government has used tax incentives to encourage domestic enterprises to commit more resources to R&D. This policy has evolved over time and is now one of the most generous incentive regimes for R&D in the world: in 2012, one-quarter of industrial R&D performed in India was subsidized (Mani, 2014). The question is, have these subsidies boosted investment in R&D by the business enterprise sector?

Public and private enterprises are certainly playing a greater role than before; they performed nearly 36% of all R&D in 2011, compared to 29% in 2005. Approximately 80% of all foreign and domestic patents granted to Indian inventors

6. Launched from Sriharikota spaceport on India's east coast, the Mangalyaan probe is studying the red planet's atmosphere in the hope of detecting methane, a potential sign of life. It will keep sending the data back to Earth until the spacecraft's fuel runs out.

7. In November 2014, the Indian Institute of Technology in Madras was accepted by CERN as a full member of its Compact Muon Selenoid (CMS) experiment, famous for its discovery of the Higgs Boson in 2013. The Tata Institute of Fundamental Research in Mumbai, Bhabha Atomic Research Centre and the Delhi and Panjab Universities have been full CMS members for years.

8. 'Achieving [a GERD/GDP ratio of 2.0%] in the next five years is realizable if the private sector raises its R&D investment to at least match the public sector R&D investment from the current ratio of around 1:3. This seems attainable, as industrial R&D investment grew by 250% and sales by 200% between 2005 and 2010... While maintaining current rates of growth in public R&D investments, a conducive environment will be created for enhancing private sector investment in R&D' (DST, 2013).

(excluding individuals) went to private enterprises in 2013. As a corollary of this trend, research councils are playing a smaller role than before in industrial R&D.

Innovation is dominated by just nine industries

More than half of business R&D expenditure is distributed across just three industries: pharmaceuticals, automotive and IT (Figure 22.3) [DST, 2013]. This implies that the subsidies have not really helped to spread an innovation[9] culture across a wider spectrum of manufacturing industries. The subsidies simply seem to have enabled R&D-intensive industries like pharmaceuticals to commit even more resources than before to R&D. The government would do well to commission a serious study into the effectiveness of these tax incentives. It should also envisage the idea of providing the business sector with grants to encourage it to develop specific technologies.

Six industries concentrate about 85% R&D. Pharmaceuticals continue to dominate, followed by the automotive industry and IT (read computer software). It is interesting to note that computer software has come to occupy an important place in the performance of R&D. Leading firms have adopted a conscious policy of using R&D to keep them moving up the technology ladder, in order to remain competitive and generate fresh patents.

9. The consultations evoked in the *UNESCO Science Report 2010* (p. 366) did not give rise to a national innovation act, as the draft bill was never presented to parliament.

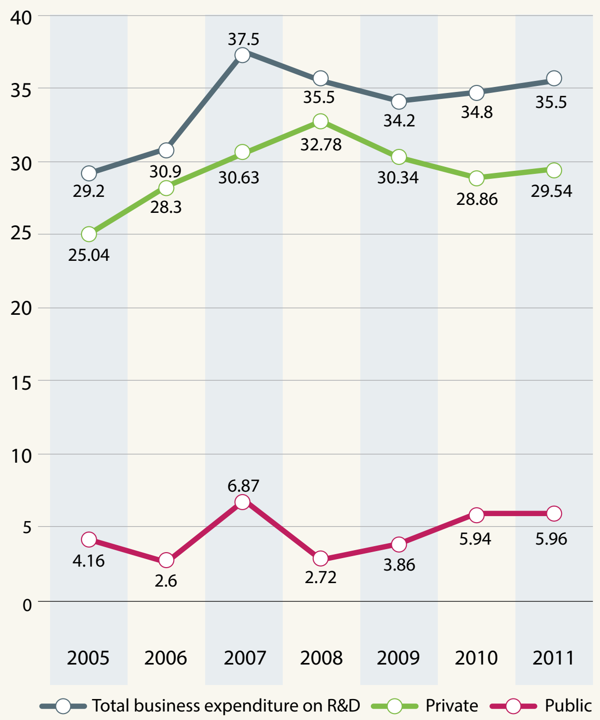
Within these six industries, R&D is concentrated in a handful of large firms. For instance, five firms account for over 80% of the R&D reported by the pharmaceutical industry: Dr Reddy's, Lupin, Ranbaxy, Cadila and Matrix Laboratories. In the automotive industry, two firms dominate: Tata Motors and Mahindra. In IT, there are three dominant firms: Infosys, Tata Consultancy Services and Wipro.

The government needs to support the emergence of technology-based start-ups to broaden the innovation culture in India. Technological progress has brought down traditional barriers which prevented SMEs from accessing technology. What SMEs need is access to venture capital. In order to encourage the growth of venture capital, the union government in its budget for 2014–2015 proposes setting up a fund of Rs 100 billion (*circa* US$ 1.3 billion) to attract private capital that could provide equity, quasi-equity, soft loans and other risk capital for start-ups.

Innovation is concentrated in just six states

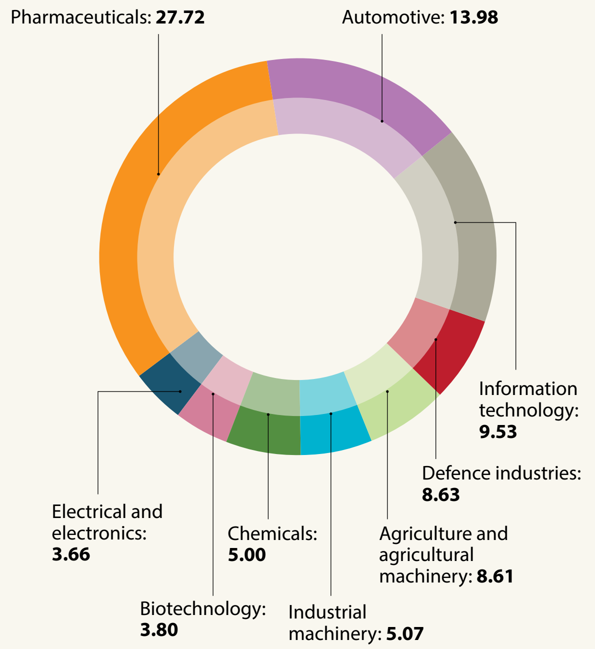
We have seen that innovation is concentrated in just nine industries. Manufacturing and innovation are also concentrated in geographical terms. Just six Indian states out of 29 account for half of R&D, four-fifths of patents and three-quarters of FDI. Moreover, even within each state, only one or two cities are research hubs (Table 22.2), despite a vigorous regional development policy in the decades leading up to the adoption by India of an economic liberalization policy in 1991.

Figure 22.2: **R&D trends in Indian public and private enterprises, 2005–2011 (%)**



Source: UNESCO Institute of Statistics; DST (2013)

Figure 22.3: **India's main industrial performers, 2010 (%)**
In terms of R&D expenditure



Note: Percentages may not add up to 100 on account of rounding.
Source: DST (2013)

Chapter 22

Table 22.2: **Distribution of innovative and manufacturing activity within India, 2010**

State	Major cities	R&D expenditure (% of total)	Patents granted (% of total)	Value-added manufacturing (% of total)	FDI (% of total)
Maharashtra	Mumbai, Pune	11	31	20	39
Gujarat	Ahmedabad, Vadodara, Surat	12	5	13	2
Tamil Nadu	Chennai, Coimbatore, Madurai	7	13	10	13
Andhra Pradesh*	Hyderabad, Vijayawada, Visakhapatnam	7	9	8	5
Karnataka	Bangalore, Mysore	9	11	6	5
Delhi	Delhi	–	11	1	14
Total for the above		46	80	58	78

Note: Andhra Pradesh was divided into two states, Telangana and Andhra Pradesh, on 2 June 2014. Located entirely within the borders of Telangana, Hyderabad is to serve as the joint capital for both states for up to 10 years.

Source: Central Statistical Organization; DST (2013); Department of Industrial Policy and Performance

Pharma companies are home-grown, IT companies are foreign

An interesting picture emerges when we analyse the output of firms in terms of the number and type of patents granted to Indians by the United States Patent and Trademark Office (USPTO). The data reveal a steep increase both in overall patenting by Indian inventors and in the share of high-tech patents; there has also been a discernible shift in technological specialization, with pharma receding in importance and IT-related patents filling the gap (Figure 22.4).

The important point here is whether these patents are owned by domestic or foreign enterprises. Almost all of the USPTO patents secured by Indian inventors do indeed belong to domestic pharmaceutical companies. As noted in the *UNESCO Science Report 2010*, domestic pharmaceutical companies increased their patent portfolio even after the international agreement on Trade-related Aspects of Intellectual Property Rights (TRIPS) was translated into Indian law in 2005. In fact, for every single indicator[10] of innovative activity, Indian pharmaceutical firms have done exceedingly well (Mani and Nelson, 2013). However, the same cannot be said for computer software or IT-related patents; as can be seen from Figure 22.4, almost all these patents are secured by multinational companies which have established dedicated R&D centres in India to take advantage of the skilled, yet cheap labour on the market in software engineering and applications. The growing importance of software-related patents among total patents indicates that foreign ownership of Indian patents has increased significantly. This is part of the trend towards a globalization of innovation, in which India and, indeed, China have become important players. We shall be discussing this important trend in more detail below.

The surge in the creation of knowledge assets at home has not reduced India's dependence on foreign knowledge assets. This is best indicated by observing India's trade in technology, as exemplified by the charges that India receives and pays for technology transactions. The difference between the technology receipts and payments gives us the technology trade balance (Figure 22.5).

India is surfing the globalization wave to develop innovation

Thanks to a surge in FDI in both manufacturing and R&D over the past five years, foreign multinational companies have been playing a growing role in innovation and patenting in India. In 2013, foreign companies represented 81.7% of domestic patents obtained from the USPTO; in 1995, they had accounted for just 22.7% of the total (Mani, 2014).

The main policy challenge will be to effect positive spillovers from these foreign companies to the local economy, something that neither the *Science, Technology and Innovation Policy* (2013), nor current FDI policies have explicitly factored into the equation.

At the same time, Indian companies have acquired knowledge assets from abroad through a wave of cross-border mergers and acquisitions. In the first wave, there was Tata's acquisition of the Corus Group plc (today Tata Steel Europe Ltd) in 2007, giving Tata access to car-grade steel technology; this was followed by the acquisition of German wind turbine manufacturer Senvion (formerly REpower Systems) by Suzlon Energy Ltd in December 2009. More recent examples are:

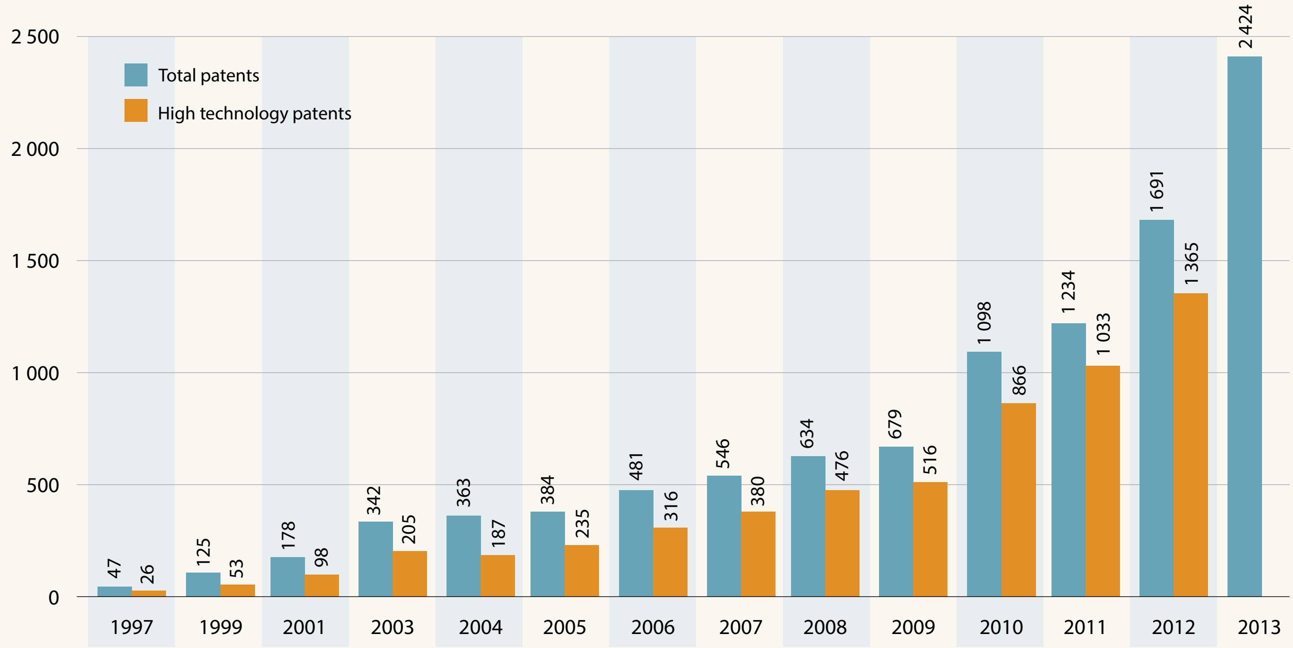
- Glenmark Pharmaceuticals' opening of a new monoclonal antibody manufacturing facility in La Chaux-de-Fonds, Switzerland, in June 2014, which supplements Glenmark's existing in-house discovery and development capabilities and supplies material for clinical development;
- Cipla's announcement in 2014 of its fifth global acquisition deal within a year, by picking up a 51% stake for US$ 21 million in a pharmaceuticals manufacturing and distribution business in Yemen;
- The acquisition by Motherson Sumi Systems Ltd of Ohio-based Stoneridge Inc.'s wiring harness business for US$ 65.7 million in 2014;

10. Be it the indicator for exports, net trade balance, R&D expenditure, patents granted within and without India or the number of Abbreviated New Drug Applications approved by the US Food and Drug Administration (implying technological capability in generic drug capability)

Figure 22.4: **Trends in Indian patents, 1997–2013**

Most patents granted to Indian inventors are in high-tech

Utility patents granted by USPTO



Source: USPTO; NSB (2014)

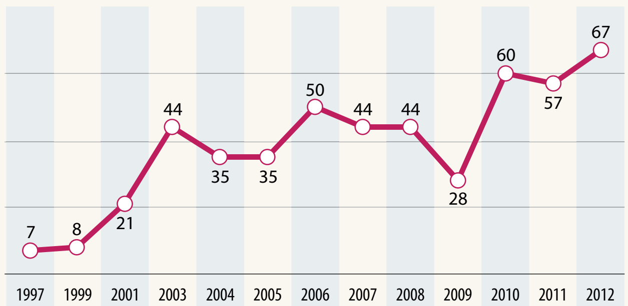
IT firms in India tend to be foreign-owned

	IT-related patents (number)			Share (%)	
	Domestic	Multi-national companies	Total	Domestic	Multi-national companies
2008	17	97	114	14.91	85.09
2009	21	129	150	14.00	86.00
2010	51	245	296	17.23	82.77
2011	38	352	390	9.74	90.26
2012	54	461	515	10.49	89.51
2013	100	1 268	1368	7.30	92.71

Source: Computed from USPTO, 2014

The number of biotech patents has doubled in a decade

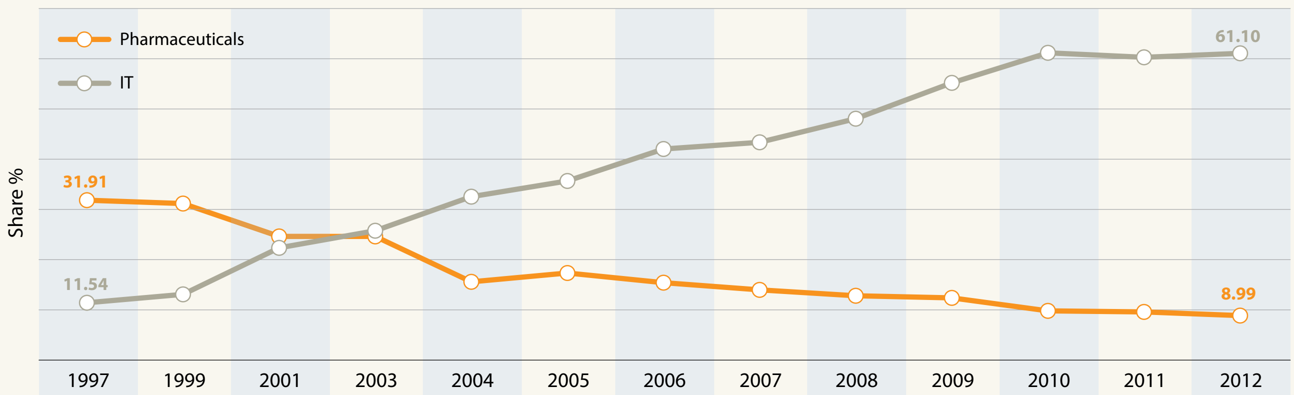
Utility patents granted by USPTO, 1997–2012



Source: based on data provided in Appendix Table 6-48, NSB (2014)

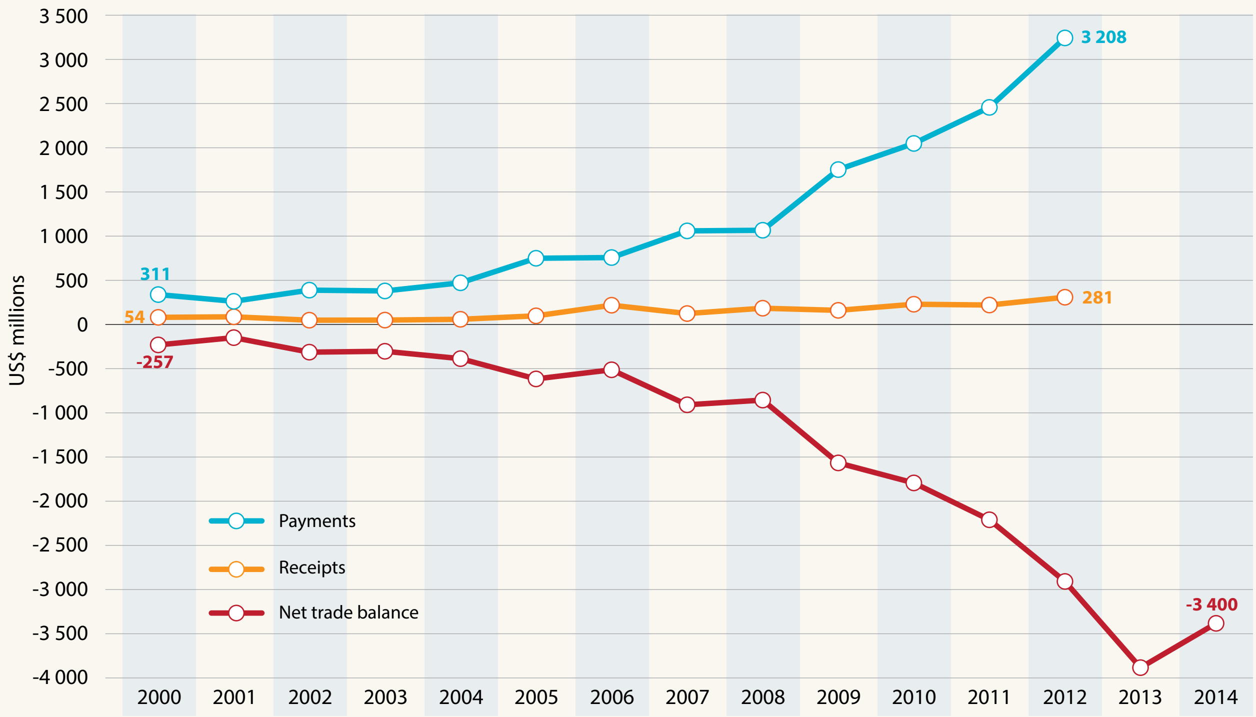
Six out of 10 patents are now in IT, one in ten in pharma

Utility patents granted by USPTO (%)



Source: Computed from USPTO, 2014

Figure 22.5: **Receipts, payments and net trade balance in the use of IPRs in India, 2000–2014**



Source: Computed from Reserve Bank of India (various issues)

- Mahindra Two Wheelers made a binding offer in October 2014 to buy a 51% stake in Peugeot Motocycles, the world's oldest manufacturer of motorized two-wheelers, from French car-maker Peugeot S.A. Group, for € 28 million (about Rs 217 crore).

This trend is very pronounced in manufacturing industries such as steel, pharmaceuticals, automotive, aerospace and wind turbines. It is also very visible in service industries such as computer software development and management consulting. In fact, these mergers and acquisitions allow late-comer firms to acquire knowledge assets 'overnight'. The government encourages firms to seize this window of opportunity through its liberal policy on FDI in R&D, its removal of restrictions on outward flows of FDI and its tax incentives for R&D. The growing globalization of innovation in India is a great opportunity, for it is turning the country into a key location for the R&D activities of foreign multinationals (Figure 22.6). In fact, India has now become a major exporter of R&D and testing services to one of the world's largest markets for these, the USA (Table 22.3).

India has become a hub for frugal innovation

Meanwhile, India has become a hub for what is known as frugal innovation. These products and processes have more or less the same features and capabilities as any other original product but cost significantly less to produce. They are most common in the health sector, particularly in the form of medical devices. Frugal innovation or engineering creates high-value products at an extremely low cost for the masses, such as a passenger car or a CAT scanner. Firms of all shapes and sizes employ frugal methods: start-ups, established Indian companies and even multinationals. Some multinationals have even established foreign R&D centres in India, in order to incorporate frugal innovation into their business model.

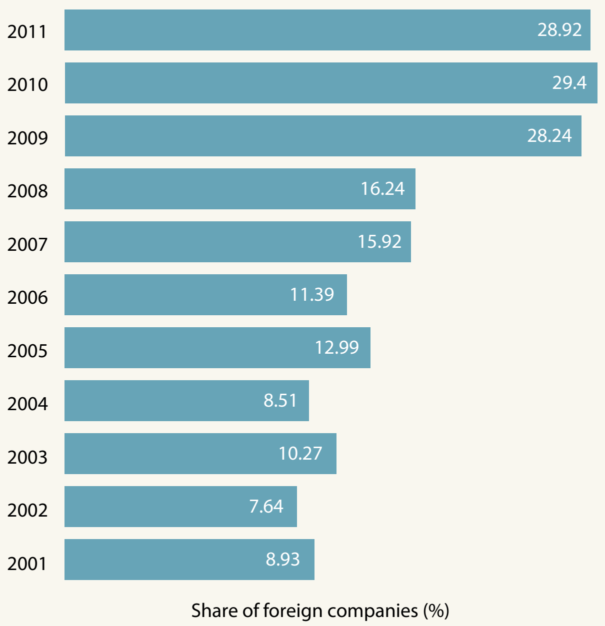
Table 22.3: **Exports of R&D and testing services from India and China to the USA, 2006–2011**

	Exports (millions of US$)			Share of national exports (%)	
	From India to the USA	From China to the USA	Total US exports from India & China	India	China
2006	427	92	9 276	4.60	0.99
2007	923	473	13 032	7.08	3.63
2008	1 494	585	16 322	9.15	3.58
2009	1 356	765	16 641	8.15	4.60
2010	1 625	955	18 927	8.59	5.05
2011	2 109	1 287	22 360	9.43	5.76

Note: This table lists only those R&D services exported from India and China by the affiliates of US multinational companies to their parent company in the USA

Source: National Science Board (2014)

Figure 22.6: **Share of foreign companies performing R&D in India (%), 2001–2011**



Source: Mani (2014)

India has not only become a hub for frugal creations; it is also codifying them then exporting them to the West.

Despite the overwhelming popularity of frugal innovation, innovation policies in India do not explicitly encourage frugal innovation. This oversight needs addressing. Nor is the phenomenon sufficiently documented. Radjou *et al*. (2012) have nevertheless managed to identify a series of goods and services which qualify as frugal innovation. These are summarized in Box 22.1 and Table 22.4.

There are seven characteristics which typify frugal innovation:

- Most products and services have emanated from large, organized firms in manufacturing and the service sector, some of which are multinationals;
- Manufactured items tend to involve a fair amount of formal R&D;
- Their diffusion rate has varied quite significantly, although relevant data are hard to come by; some of the most celebrated examples of frugal innovation, like Tata's micro-car, the Nano, do not seem to have been accepted by the market;
- Whenever frugal engineering implies the removal of key features, it is unlikely to succeed; it is this which may explain the poor sales of the first Nano car; the latest model, the Nano Twist, comes with a number of features found in more expensive models, such as an electric power-assisted steering system;
- Frugal services tend not to involve any R&D, or not of a sophisticated nature at least, nor any new investments or technology; they may simply be an innovation in the way the supply chain is organized;
- Services or processes may be very location-specific and as such not replicable elsewhere; for instance, the celebrated *Mumbai Dabbawalas* (lunch box delivery service in Mumbai) has never spread to other Indian cities, despite being considered an efficient process for managing the supply chain; and
- Among the known products transferred to the West from India, most concern medical devices.

Box 22.1: **Frugal innovation in India**

Making do with less in goods manufacturing and services has long been an accepted and inescapable reality in India. Following the proverbial idiom, 'necessity is the mother of invention', improvisation – better known by its Hindi equivalent of *jugaad* – has always been a way of getting things done.

Although poverty rates in India have come down, one in five Indians still lives below the poverty line (Table 22.1). India remains the country with the largest number of poor citizens: more than 270 million in 2012.

To serve the mass of consumers at the bottom of the pyramid, India's quality goods and services need to be affordable. This has given rise to what is increasingly being termed frugal innovation or frugal engineering.

Although frugal innovations are spread across a range of manufacturing and service industries, they most often take the form of medical devices. This phenomenon has received a fillip from the Stanford–India Biodesign Project (SIBDP) involving the University of Stanford in the USA. Initiated in 2007, this programme has spawned a number of entrepreneurs whose innovative medical devices have low production costs (Brinton *et al*., 2013), qualifying them as frugal innovations. In its eight years of existence, SIBDP has produced four particularly interesting start-ups in medical devices in India. These have developed a novel integrated neonatal resuscitation solution, a non-invasive safe device for screening newborns for a hearing impairment, low-cost limb immobilization devices for treating road traffic accident injuries and an alternative to difficult intravenous access in medical emergencies.

Source: compiled by author

Table 22.4: **Examples of frugal innovation in India**

INNOVATION	COMPANY INVOLVED IN DEVELOPMENT	DIFFUSION
GOODS		
MICRO-PASSENGER CAR, THE TATA NANO This product has a virtual monopoly in its niche market. The original Nano cost about US$ 2 000.	**Tata**	Very low acceptance rate, as indicated by the declining sales. The car was marketed from 2009 onwards. Sales peaked at 74 521 in 2011–2012. The following year, they fell to 53 847 then to just 21 130 in 2013–2014.
SOLAR-POWERED GSM BASE STATION This system enables people in rural areas to use mobile phones. The World Global System for Mobile Communications (WorldGSM™) is the first commercially viable GSM system that is independent of the power grid. It runs exclusively on solar power and requires no backup from a diesel generator. It is also designed for simple delivery and deployment by local, untrained workers.	**VNL Limited**	No data on its deployment
PORTABLE ELECTROCARDIOGRAM (ECG) MACHINE This machine (GE MAC 400) costs about US$ 1 500 and weighs about 1.3 kg, compared to US$ 10 000 and about 6.8 kg for a regular ECG machine.	**General Electric Healthcare**	There are no data on its diffusion. However, the product is very well accepted by the market and General Electric has exported this technology to its parent firm in the USA.
PORTABLE TOP LOADING REFRIGERATOR It has a capacity of 35 litres, runs on batteries and is priced at about US$ 70. It can be used in villages for storing fruit, vegetables and milk. It is known as *Chotukool*.	**Godrej**, an Indian company	In order to diffuse the technology, Godrej has joined forces with India Post. There are unconfirmed reports of 100 000 pieces having been sold in the first two years of production.
LOWEST POWER-CONSUMING AUTOMATIC TELLER MACHINE (ATMS) This machine is solar-powered and goes by the name of Gramateller.	**Vortex**, an Indian company, and the **Indian Institute of Technology Madras**	Leading banks such as the State Bank of India, HDFC and Axis Bank have adopted Vortex-designed and manufactured ATMs to service their rural customers.
ALTERNATIVE HOME-COOKING FUEL AND STOVE Oorja combines a micro-gasification device or stove with a biomass-based pellet fuel.	**First Energy**, an Indian company	According to the company's website, it has about 5 000 customers.
SERVICES		
LARGE-SCALE, CHEAP EYE SURGERY	**Arvind Eye Care System**	During 2012–2013, the hospital performed 371 893 surgical acts.
LOW-COST MATERNITY HOSPITALS These hospitals provide quality maternity health care at 30–40% of the market price.	**Life Spring**	Life Spring currently operates 12 hospitals in the city of Hyderabad, with plans to expand to other cities.
LOW-COST FINANCIAL SERVICES Eko leverages existing retail shops, telecom connectivity and banking infrastructure to extend branchless banking services to the person in the street. Eko also partners with institutions to offer payment, cash collection and disbursal services. Customers can walk up to any Eko counter (retail outlet) to open a savings account, deposit and withdraw cash from the account, send money to any part of the country, receive money from any part of the world, buy mobile talk-time or pay for a host of services. A low-cost mobile phone acts as the transaction device for retailers and customers.	**Eko**	Detailed number of Eko counters opened and functioning unavailable

Source: compiled by author

TRENDS IN GOVERNMENT RESEARCH

The government sector is the main employer of scientists

If you take a group of 100 researchers in India, 46 will work for the government, 39 for industry, 11 for academia and 4 for the private non-profit sector. This makes the government the main employer. The government sector also spends the majority of the R&D budget (60%), compared to 35% for industry and just 4% for universities.

The government organizes its R&D through 12 scientific agencies and ministries. These have performed about half of GERD since 1991 but much of their output has little connection with business enterprises in either the public or private sectors. One-quarter of research in the government sector is devoted to basic research (23.9% in 2010).

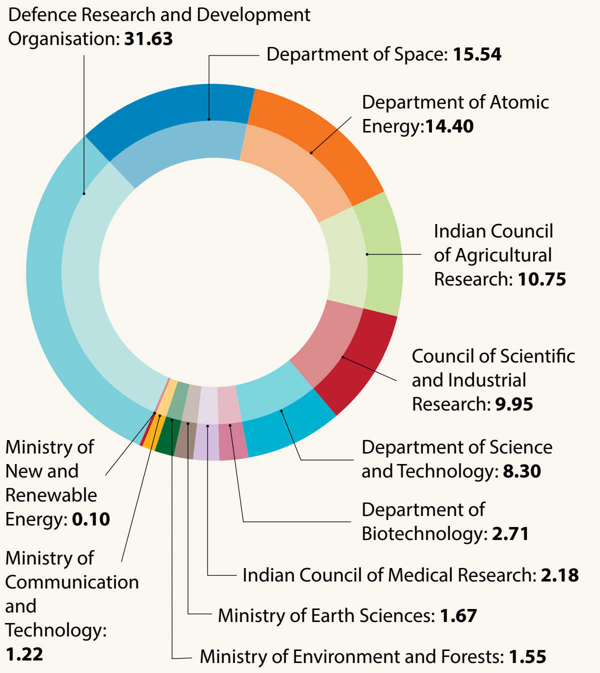
The Defence Research and Development Organisation (DRDO)[11] alone accounts for about 17% of GERD and just under 32% of the government outlay in 2010, twice as much as the next biggest agency, the Department of Atomic Energy, which nevertheless increased its share from 11% to 14% between 2006[12] and 2010, at the expense of DRDO and the Department of Space. The government has raised funding levels for the Council of Scientific and Industrial Research (CSIR) slightly (9.3% in 2006), at the expense of the Indian Council of Agricultural Research (11.4% in 2006). The smallest slice of the pie continues to go to the Ministry of New and Renewable Energy (Figure 22.7).

A first: defence technologies will be adapted to civilian use

Almost the entire output of defence R&D goes to the military for the development of new forms of weaponry, like missiles. There are very few recorded instances of defence research results being transferred to civilian industry, unlike in the USA where such transfers are legendary. One example of this wasted technological capability is the loss to India's aeronautical industry, where a considerable amount of technological capability has been built around military aircraft without any transfer to civilian craft.

This state of affairs is about to change with the launch of a joint initiative in 2013 by DRDO and the Federation of Indian Chambers of Commerce and Industry (FICCI) for Accelerated Technology Assessment and Commercialization[13]. The aim is to create a commercial channel for orienting technologies developed by DRDO towards national and international commercial markets for civilian use. This programme is the first of its kind for DRDO. As many as 26 DRDO labs across India were participating in the programme in 2014, while FICCI assessed over 200 technologies from sectors as diverse as electronics, robotics, advanced computing and simulation, avionics, optronics, precision engineering, special materials, engineering systems, instrumentation, acoustic technologies, life sciences, disaster management technologies and information systems.

Figure 22.7: **Government outlay for India's major science agencies, 2010 (%)**



Source: DST (2013)

A new Academy of Scientific and Innovative Research

The CSIR has a network of 37 national laboratories which undertake cutting-edge research across a vast spectrum of fields, including radio and space physics, oceanography, drugs, genomics, biotechnology, nanotechnology, environmental engineering and IT. CSIR's 4 200 scientists (3.5% of the country's total) bat above their weight, authoring 9.4% of India's articles in the Science Citation Index. The rate of commercialization of patents emanating from CSIR laboratories is also above 9%, compared to a global average of 3–4%.[14] Despite this, CSIR scientists interact little with industry, according to the Comptroller and Auditor General.

In order to improve its profile, the CSIR has put in place three broad strategies since 2010. The first consists in combining the skill sets in a range of its laboratories to create networks for the execution of a specific project. The second strategy consists in setting up a series of innovation complexes to foster interaction with micro-enterprises and SMEs, in particular. So far, three

11. India has the world's 3rd-biggest armed forces and is the 10th-biggest spender on defence. The defence budget represented 2.4% of GDP in 2013, compared to 2.9% in 2009, according to the World Bank.

12. See the *UNESCO Science Report 2010* for the complete 2006 data (p. 371).

13. This programme is one of four executed by the Centre for Technology Commercialization, which was set up by FICCI in 2006. For details, see: https://thecenterforinnovation.org/techcomm-goes-global

14. These figures are based on an answer to question no. 998 in the upper house of India's parliament, the *Rajya Sabha*, on 17 July 2014.

innovation complexes have been established in Chennai, Kolkatta and Mumbai. The third strategy consists in offering postgraduate and doctoral degrees in highly specialized fields where such training is not easily available in traditional universities; this led to the establishment of the Academy of Scientific and Innovative Research in 2010, which recently awarded its first master's degrees and PhDs in science and engineering.

India's scientific councils can call upon the services of the National Research and Development Corporation (NRDC). It functions as a link between scientific organizations and industries eager to transfer the fruits of endogenous R&D to industry. The NRDC has a number of intellectual property and technology facilitation centres and, on campuses around the country in major Indian cities, university innovation facilitation centres. The NRDC has transferred approximately 2 500 technologies and approximately 4 800 licensing agreements since its inception in 1953. The number of technologies licenced by NRDC increased from 172 during the *Eleventh Five-year Plan* period (2002–2007) to 283 by 2012. Despite these apparent instances of technology transfer, NRDC is not generally considered as having been successful in commercializing technologies generated by the CSIR system.

Funding not an issue in falling food crop yields

Since the turn of the century, wheat yields have dropped and rice yields have stagnated (Figure 22.8). This worrying trend does not seem to be tied to any cutbacks in funding. On the contrary, agricultural funding has increased, whatever the point of comparison: in nominal and real terms, aggregate and per capita terms and against public funding of industrial research. Even the percentage share of agricultural research in agricultural GDP shows an increase over time. So funding *per se* does not appear to be an issue.[15] An alternative explanation for this drop in yield may well be the observed decline in the numbers of agricultural scientists in India, including lower enrolment ratios in graduate degree programmes in agriculture. This state of affairs has prompted the government to propose two key measures in the union budget for 2014–2015 for the training of agricultural scientists and engineers:

- The establishment of two more centres of excellence, modelled on the lines of the Indian Agricultural Research Institute, one in the city of Assam and a second in Jharkhand, with an initial budget of Rs 100 crores (*circa* US$ 16 million) for 2014–2015; an additional amount of Rs 100 crores is being set aside for the establishment of an AgriTech Infrastructure Fund;
- The establishment of two universities of agriculture in Andhra Pradesh and Rajasthan and a further two universities of horticulture in Telangana and Haryana; an initial sum of Rs 200 crores has been allocated for this purpose.

15. This statement is corroborated by Pal and Byerlee (2006) and Jishnu (2014).

Growing private investment in agricultural R&D

Another interesting aspect is the rising share of private R&D in agriculture, primarily in seeds, agricultural machinery and pesticides. This trend does not have the same implications as an increase in public-sector investment in agricultural R&D would have, as the products generated by private R&D are likely to be protected by various mechanisms governing intellectual property rights, thereby increasing the cost of their diffusion to farmers.

The diffusion of genetically modified organisms (GMOs) among food crops has been curtailed for health and safety reasons by the Genetic Engineering Appraisal Committee of the Ministry of Environment and Forests. The only GM crop approved in India is *Bt* cotton, which was authorized in 2002. The area cultivated with *Bt* cotton had progressed to saturation level by 2013 (Figure 22.8). India has become the world's top exporter of cotton and its second-biggest producer; cotton is a thirsty crop, however, and water a scarce commodity in India. Moreover, despite the increase in the average yield of cotton, there have been sharp fluctuations from one year to the next. The use of fertilizer and the spread of hybrid seeds may also have contributed to the rise in yield since 2002. More recently, the Indian Council of Agricultural Research has developed a *Bt* cotton variety cheaper than Monsanto's with re-usable seeds.

The proposed extension of GMOs to food crops like *brinjals* (aubergine) has met with stiff resistance from NGOs and elicited words of caution from the parliamentary Committee on Agriculture in 2012. India's own GMO research has been focusing on a range of food crops but with an emphasis on vegetables: potato, tomato, papaya, watermelon, castor, sorghum, sugar cane, groundnut, mustard, rice, etc. As of early 2015, no GM food crops had been released for cultivation pending clearance from the regulatory agencies.

A sustainable farming method challenges modern technologies

Sustainable forms of agriculture have been reported from isolated parts of the country. The world's most productive rice paddy farmer even comes from the state of Bihar in northeastern India. The farmer in question broke the world record not through modern scientific technologies but rather by adopting a sustainable method pioneered by NGOs known as the System of Rice Intensification. Despite this feat, diffusion of this method has been very limited (Box 22.2).

The biotech strategy is beginning to pay off

Biotechnology is the eighth of India's nine high-tech industries (Figure 22.3) and receives 2.7% of the government's outlay for the 12 science agencies (Figure 22.7). Consistent policy support over the past two decades has allowed India to develop sophisticated R&D and a production capability to match. The Department of Biotechnology's strategy has three

Box 22.2: The world's most productive paddy farmer is Indian

Sumant Kumar, an illiterate young farmer from the village of Darveshpura in the State of Bihar, is now acknowledged as being the most productive paddy farmer in the world. He managed to grow 22 tonnes of rice from a single hectare, compared to a world average of 4 tonnes, by adopting the System of Rice Intensification (SRI). The previous record of 19 tonnes was held by a Chinese farmer.

SRI allows farmers to produce more from less. In other words, it is an example of frugal innovation. Five key characteristics differentiate it from conventional practices:

- the use of a single seedling instead of clumps;
- the transplanting of seedlings at a young age of less than 15 days;
- wider spacing in square planting;
- rotary weeding; and
- a greater use of organic manures.

The application of these five elements promises numerous advantages, including higher yield and a lesser requirement for both seeds and water.

SRI is thus ideally suited for countries like India where farmers are poor and water is extremely scarce.

SRI's origins date back to the early 1980s when Henri de Laulanié, a French Jesuit priest and agronomist, developed the method after observing how villagers grew rice in the uplands of Madagascar.

According to a study by Palanisami *et al.* (2013) of 13 major rice-growing states in India, fields which have adopted SRI have a higher average productivity than those which have not.

Out of the four core SRI components typically recommended, 41% of SRI farmers have adopted one component, 39% two or three components and only 20% all the components. Full adopters recorded the highest yield increase (3%) but all adopters had yields higher than conventional farmers. They also had higher gross margins and lower production costs than non-SRI fields.

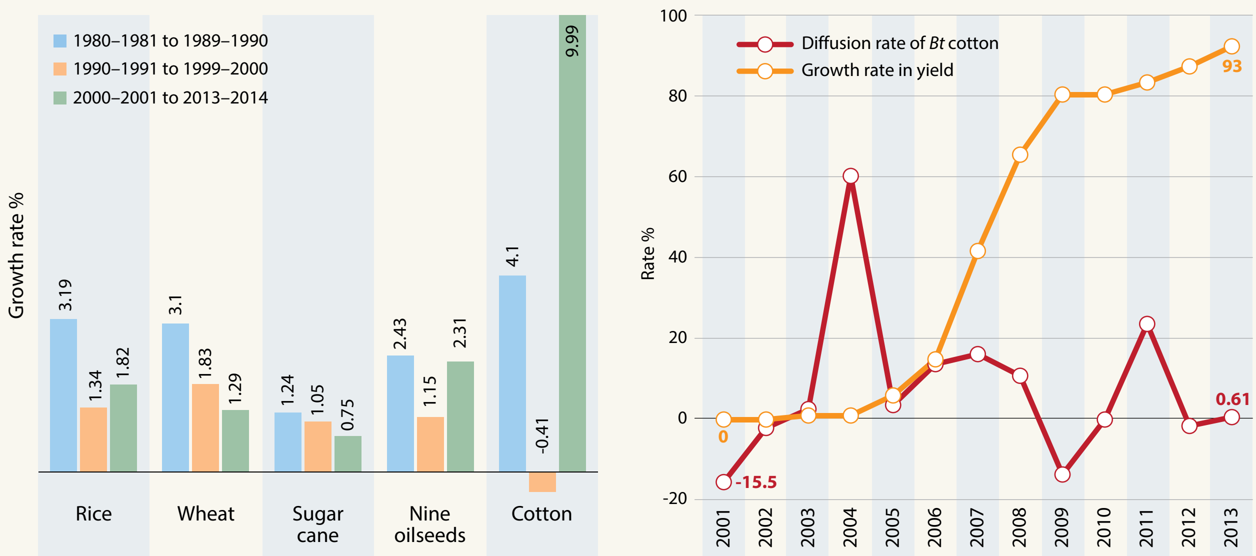
Although India's rice yield could significantly increase under SRI and modified SRI practices, a number of hurdles will first have to be overcome, according to the authors, namely a lack of skilled farmers available in time for planting operations, poor water control in the fields and unsuitable soils. Moreover, farmers also feel that the transaction (managerial) cost, although insignificant, still limits full adoption of SRI. Government intervention will thus be necessary to overcome these constraints.

Source: SRI International Network Resource Center (USA); Palanisami *et al.* (2013); www.agriculturesnetwork.org

Figure 22.8: **Changes in agricultural yields in India, 1980–2014**

Average annual growth in yield for key food crops in India, 1980–2014 (%)

Diffusion rate of Bt cotton and growth in cotton yield, 2001–2013



Note: The diffusion rate for *Bt* cotton resembles the familiar S-shaped pattern noted by many observers of the rate of diffusion of new technologies.

Source: Based on Table 8.3, Ministry of Finance *(2014) Economic Survey 2013–2014*

Source: VIB (2013)

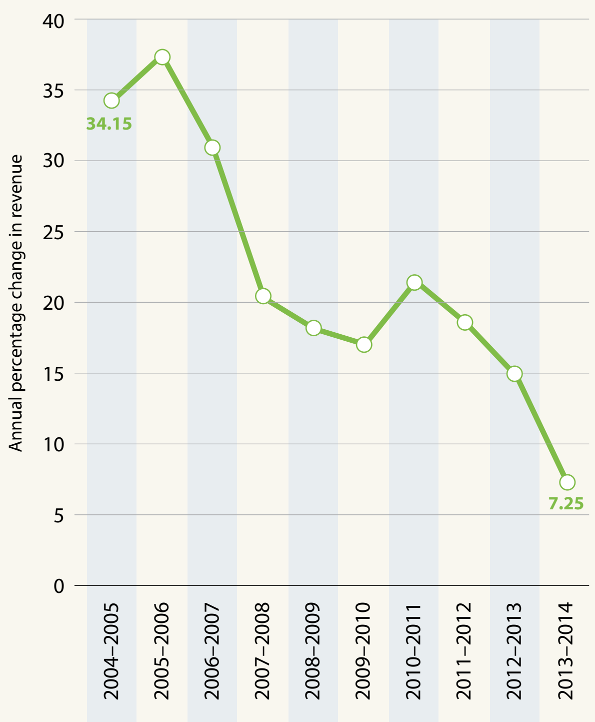
thrusts: improving the quantity and quality of human resources in biotechnology; establishing a network of laboratories and research centres to work on relevant R&D projects; and creating enterprises and clusters to produce biotechnology products and services. Apart from the central government, several state governments have explicit policies for developing this sector. This has led to a surge in biotech-related publications and patents (Figure 22.4).

The biotechnology industry has five subsectors: biopharmaceutical (63% of total revenue in 2013–2014), bioservices (19%), agricultural biotech (13%), industrial biotech (3%) and bioinformatics (1%). The biotechnology industry grew by an average rate of 22% per annum between 2003 and 2014, although year-on-year growth rates show a declining trend (Figure 22.9).[16] Approximately 50% of output is exported. The Department of Biotechnology is building a Biotech Science Cluster in Faridabad on the outskirts of the capital. The cluster includes the Translational Health Science Technology Institute and the Regional Centre for Biotechnology, the first of its kind in South Asia. The regional centre functions under the auspices of UNESCO, offering specialized training and research programmes in 'new opportunity areas' such as cell and tissue engineering, nanobiotechnology and bioinformatics. The emphasis is on interdisciplinarity, with future physicians taking courses in biomedical engineering, nanotechnology and bio-entrepreneurship.

16. These rates are computed using sales revenue in Indian rupees at current prices. However, if one were to convert these to US dollars and recompute the growth rates, the industry would have been near-stagnant since 2010. There are, however, no official surveys or data on the size of India's biotechnology industry.

Figure 22.9: **Growth of the Indian biotechnology industry, 2004–2014**

Based on sales revenue at current prices



Source: Computed from the Association of Biotech Led Enterprises (ABLE), Biospectrum Survey changes in sales revenue at current prices

India is making a foray into aircraft manufacturing

Exports of high-tech manufactured products are increasing and now account for about 7% of manufactured exports (World Bank, 2014). Pharmaceuticals and aircraft parts account for almost two-thirds of the total (Figure 22.10). India's technological capability in pharmaceuticals is fairly well known but her recent forays into the manufacturing of aircraft parts are a step into the unknown.

Recent elaborations of the Defence Purchase Policy[17] and the policy on offsets seem to have encouraged local manufacturing. For instance, India is developing a regional transport aircraft through a mission-mode National Civil Aircraft Development project. Although largely initiated by the public sector, the project envisages participation by domestic private sector enterprises as well.

India is also continuing to improve its capability in the design, manufacture and launch of satellites[18] and has ambitious plans for sending people to the Moon and exploring Mars.

India is deploying more high-tech services

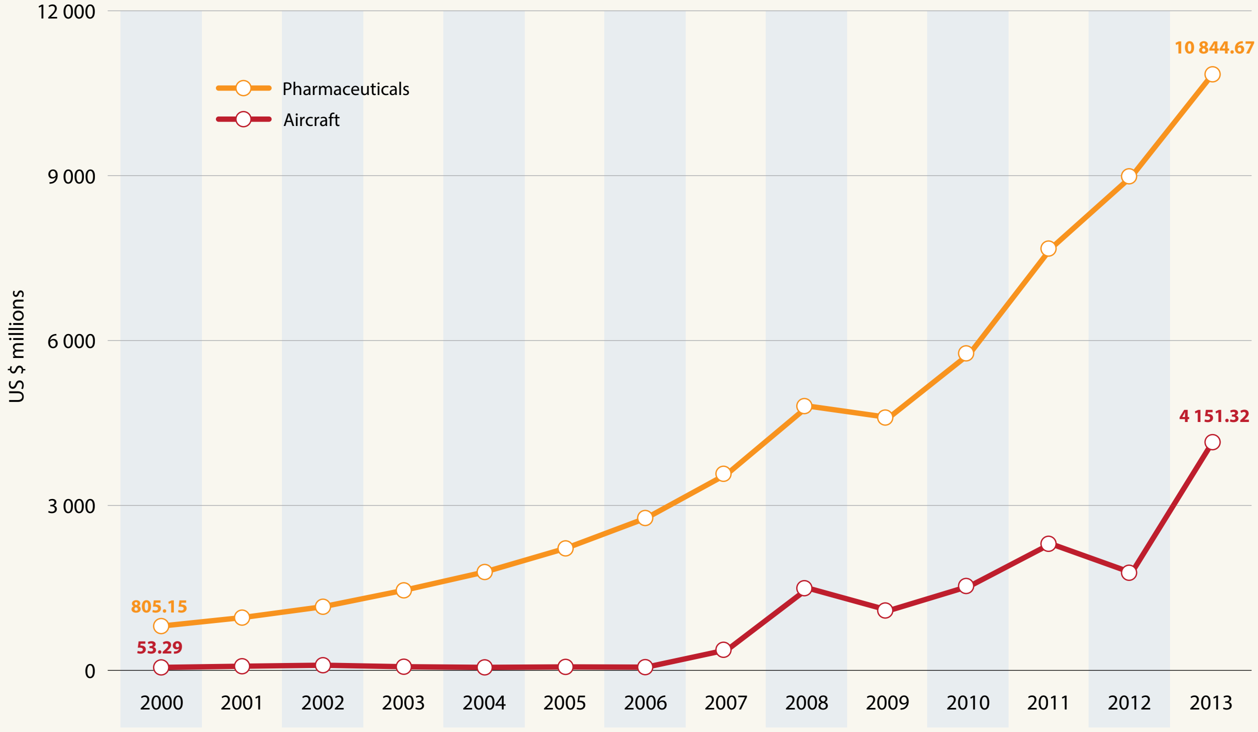
Considerable improvements have been made in both the astronautic and even in the aeronautical segments of the IT industry. Leveraging capabilities in communication technologies and remote sensing, the country has made big strides in diffusing distance education and public health interventions. Over the years, the Indian Space Research Organisation's telemedicine network has expanded to connect 45 remote and rural hospitals and 15 highly specialized hospitals. The remote/rural nodes include the offshore islands of Andaman and Nicobar and Lakshadweep, the mountainous and hilly regions of Jammu and Kashmir, including Kargil and Leh, Medical College hospitals in Orissa and some of the rural / district hospitals in the mainland states.

Big strides have been made in telecommunications services as well, especially in rural areas. India has shown by example that the best way of diffusing telecommunications in rural areas is to foster competition between telecom service providers, which react by lowering their tariffs.

17. India procures about 70% of its equipment needs abroad. The government adopted a defence procurement policy in 2013 which gives preference to indigenous production by Indian firms or within joint ventures.

18. For more on India's space programme, see the box entitled A Space Odyssey in the *UNESCO Science Report 2010*, p. 367.

Figure 22.10: **Exports of high-tech manufactured products from India, 2000–2013**



Source: Compiled from UN Comtrade database and World Bank's World Development Indicators

The consequence has been a dramatic improvement in teledensities, even in rural areas. This is best indicated by the rising ratio of rural to urban teledensities, which grew from 0.20 to 0.30 between 2010 and 2014.

Plans to become a nanotech hub by 2017

In recent years, the government has paid growing attention to nanotechnology.[19] A Nano Mission Project was launched in India by the *Eleventh Five-Year Plan* (2007–2012), with the Department of Science and Technology serving as a nodal agency. A sum of Rs 100 billion was sanctioned over the first five-year period to build R&D capabilities and infrastructure i n nanotechnology.

The *Twelfth Five-Year Plan* (2012–2017) aims to take this initiative forward, in order to make India a 'global knowledge hub' in nanotechnology. To this end, a dedicated institute of nanoscience and technology is being set up and postgraduate programmes in 16 universities and institutions across the country are due to be launched. The Nano Mission Project is also funding a number of basic research projects[20] centred on individual scientists: for 2013–2014, about 23 such projects were sanctioned for a three-year period; this brings the total number of projects funded since the Nano Mission's inception to about 240.

The Consumer Products Inventory maintains a live register of consumer products that are based on nanotechnology and available on the market (Project on Emerging Nano Technologies, 2014). This inventory lists only two personal care products that have originated from India and the firm which developed these products is a foreign multinational. However, the same database lists a total of 1 628 products around the world, 59 of which come from China.

In 2014, the government set up a nanomanufacturing technology centre within the existing Central Manufacturing Technology Institute. In its union budget for 2014–2015, the government then announced its intention to strengthen the centre's activities through a public–private partnership.

In short, nanotechnology development in India is currently oriented more towards building human capacity and physical infrastructure than the commercialization of products, which remain minimal. As of 2013, India ranked 65th worldwide for the number of nano-articles per million inhabitants (see Figure 15.5).

19. See Ramani et al. (2014) for a survey of nanotechnology development in India.

20. The Nano Mission has so far produced 4 476 papers published in SCI journals, about 800 PhDs, 546 M.Tech and 92 MSc degrees (DST, 2014, p. 211). See also: http://nanomission.gov.in and, for the top 30 worldwide for the volume of nano-related articles in 2014, Figure 15.5

Eight states out of 29 have explicit green energy policies

India's innovation policy seems to be independent from other important economic development strategies like the *National Action Plan on Climate Change (2008)*. The level of public investment in green energy sources is also modest, with the budget for the Ministry of New and Renewable Energy representing just 0.1% of the total government outlay in 2010 (Figure 22.7). The government is nevertheless encouraging power generation through various renewable energy programmes, such as wind, biomass, solar and small hydropower. It has also designed a mix of fiscal and financial incentives and other policy/regulatory measures to attract private investment. However, all this is confined to the central government level; only eight states[21] out of 29 have explicit green energy policies.

Some Indian enterprises have acquired considerable technological capability in the design and manufacture of wind turbines, which is by far the most important source of grid-connected green technologies (76%). India, with an installed capacity of 18 500 MW, is the fifth-largest wind energy producer in the world, with considerable research and manufacturing capabilities. In 2013, three-quarters of India's installations were based on wind technology, the remainder being in small hydropower and biomass (10% each) and solar energy (4%). Since 2010, the number of patents granted in green technologies has risen sharply (Figure 22.11).

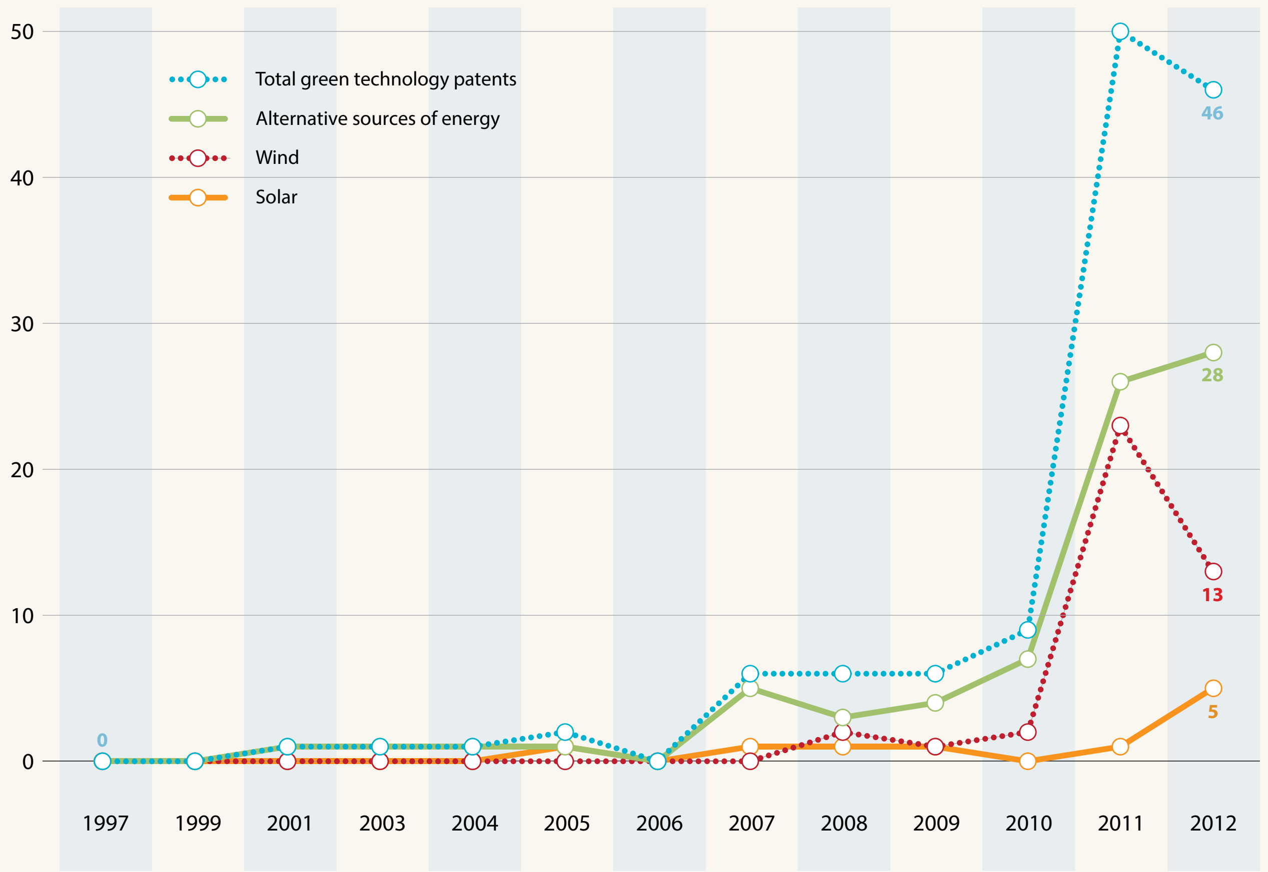
A first green bond to enrich the domestic energy mix

In February 2014, the Indian Renewable Energy Development Agency (IREDA)[22] issued its first 'green bond,' with terms of 10, 15 and 20 years and interest rates of just over 8%. The tax-free bond is open to both public and private investors. The Modi administration is targeting an investment of US$ 100 billion to help reach its goal of installing 100 gigawatts of solar energy across India by 2022. It has announced plans to train a 50 000-strong 'solar army' to staff new solar projects. In addition, a new National Wind Mission was announced in 2014 which is likely to be modelled on the National Solar Mission implemented by IREDA since 2010 (Heller *et al.,* 2015).

21. Andhra Pradesh, Chattisgarh,, Gujarat, Karnataka, Madhya Pradesh, Rajasthan, Tamil Nadu and Uttar Pradesh

22. Established in 1987, IREDA is a government enterprise administered by the Ministry of New and Renewable Energy. See: www.ireda.gov.in

Figure 22.11: **Green energy technology patents granted to Indian inventors, 1997–2012**



Source: Based on appendix tables 6-58, 6.64 and 66 in NSB (2014)

TRENDS IN HUMAN RESOURCES

The private sector is hiring more researchers

If the number of R&D personnel[23] in India increased annually by 2.43% between 2005 and 2010, this was entirely due to the 7.83 % increase each year in R&D personnel working for private companies. Over the same period, the number of government employees engaged in R&D actually declined, even though the government remains the largest employer of R&D personnel (Figure 22.12). This trend further substantiates the claim that India's national innovation system is becoming increasingly business-oriented.

This translates into a rise in the number of R&D personnel per 10 000 labour force from 8.42 in 2005 to 9.46 in 2010. This means that India still has a long way to go to reach the density achieved by developed countries and China.

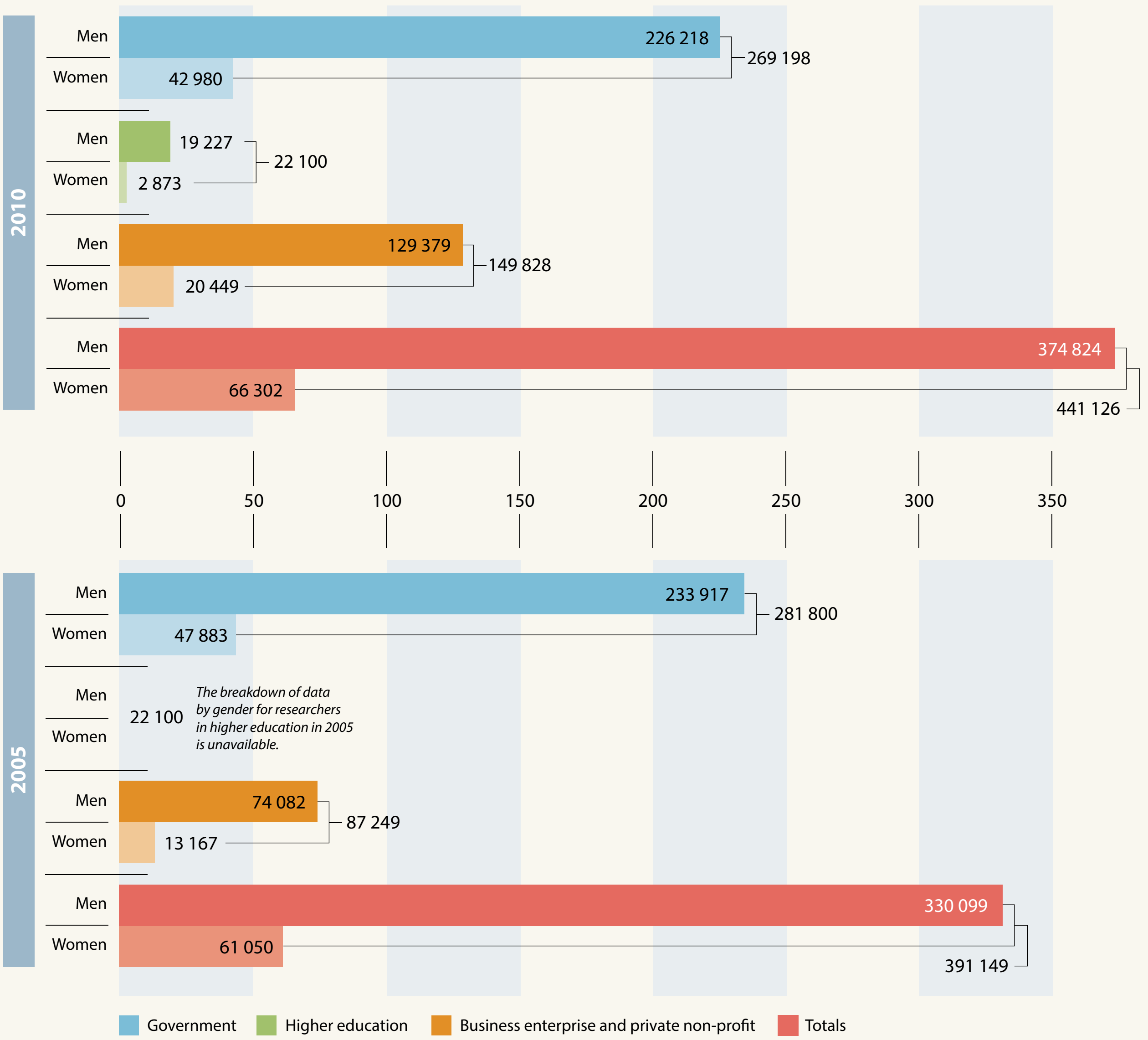
Spectacular growth in the number of engineering students

The shortage of R&D personnel could hold India back on its climb up the technology ladder. Policy-makers are fully cognisant of this problem[24] and have been putting in place a host of policies to boost university student rolls in science and

23. The term R&D personnel encompasses researchers, technicians and support staff.

24. Two of the key elements of the *Science, Technology and Innovation Policy of 2013* are: enhancing skills for applications of science among the young from all social strata; and making careers in science, research and innovation attractive for talented and bright minds.

Figure 22.12: **Indian FTE researchers by sector of employment and gender, 2005 and 2010**



Source: DST (2009; 2013)

engineering programmes. One of these schemes, INSPIRE, focuses in particular on developing a vocation for science among the young (Box 22.3).

Historically, India has tended to produce eight scientists for every engineer. This is partly a consequence of the uneven distribution of engineering colleges across different states, a situation which has prompted the government to double the number of Indian Institutes of Technology to 16 and to set up five Indian Institutes for Science Education and Research.[25] Whereas there were 1.94 scientists for every engineer in 2006, this ratio had dropped to 1.20 by 2013.

In 2012, there were 1.37 million graduates in science, engineering and technology (Figure 22.13). Men made up about 58% of the total. Female students tend to be more concentrated in science streams, where they even outnumbered their male counterparts in 2012. There is already a sizeable share of engineering and technology students but it will be important for the country to raise the number of graduates in these fields, if it wishes to forge ahead with the desired expansion in manufacturing.

A need to give employers the skills they want

The employability of scientists and engineers has been a nagging worry for policy-makers for years and, indeed, for prospective employers. The government has put in place a number of remedial measures to improve the quality of higher education (Box 22.3). These include a stricter control over universities, regular audits of the curriculum and facilities and faculty improvement programmes. The establishment of the Science and Engineering Research Board in 2010 has further fluidified the availability of research grants in the public science system.

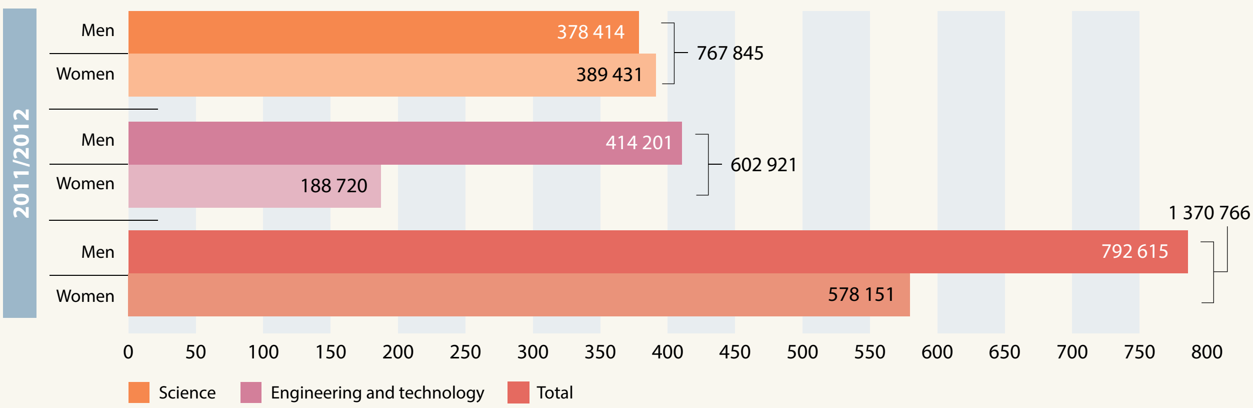
The government is also experimenting ways of fostering university–industry ties. In 2012, for example, it partnered with the Confederation of Indian Industry to incite doctoral students to team up with industry for their doctoral thesis. Successful applicants are awarded twice the usual amount for doctoral fellowships for their thesis, as long as the project is initiated by their industrial partner.

The diaspora is being wooed for technology-based projects

Another age-old issue concerns the migration of highly skilled workers. Although this phenomenon has been around since India gained independence in the 1940s, globalization has accentuated this trend over the past two decades or so. Mani (2012) has shown that, although high skilled migration may diminish the supply of scientists and engineers, it does generate a fair amount of remittances. In fact, India has become the largest receiver of remittances in the world. Skilled Indians living abroad have also helped India's high-tech industries to grow, particularly its computer software services industry. A number of schemes have been put in place to encourage the diaspora to participate in technology-based projects. One of the most long-running of these is the Ramalingaswami Re-Entry Fellowship in biotechnology, set up in 2006. In 2013, 50 researchers from the diaspora were offered a place in Indian institutions as part of this scheme.

25. In all, 172 universities were established between March 2010 and March 2013, bringing the total to 665 (DHE, 2012; 2014). None of the new institutions is a designated 'innovation university,' despite the government's intention of setting up 14 such universities. See the *UNESCO Science Report 2010*, p. 369.

Figure 22.13: **Indian science, engineering and technology graduates, 2011/2012**



Note: Graduates include undergraduates, postgraduates, MPhil and PhD holders

Source: Compiled from Department of Higher Education (2012) *All India Survey of Higher Education 2011/2012,* Tables 36 and 37

Box 22.3: Schemes to improve higher education in India

Indian universities are absent from the top places in international rankings. There is also a general feeling in India that the quality of the higher education system leaves much to be desired. Prospective employers have been complaining recently about the employability of the graduates churned out by local universities and colleges. In addition, just 4% of R&D in India is performed by the university sector. The government has put various schemes in place in the past decade to improve the quality of both university teaching and research. The following are some examples:

Rashtriya Uchchatar Shiksha Abhiyan (RUSA) was launched by the Ministry of Human Resource Development in October 2013. It aims to ensure that public universities and colleges conform to prescribed norms and standards and that they adopt accreditation as a mandatory quality assurance framework. Certain academic, administrative and governance reforms are a precondition for receiving funding under RUSA. All funding disbursed under RUSA is norm-based and outcome-dependent;

Further to the recommendations of the *Eleventh Five-Year Plan* (2007–2012), the University Grants Commission (UGC) introduced the semester system and a Choice-based Credit System at undergraduate level to give students a wider range of choices beyond their study discipline, offer them exposure to the world of work through internships and vocational training and enable them to transfer credits to another university.

In 2010, UGC issued regulations on *Minimum Qualifications for the Appointment of Teachers and other Academic Staff in Universities and Colleges and Measures for the Maintenance of Standards in Higher Education*. Two years later, it issued regulations for the *Mandatory Assessment and Accreditation of Higher Educational Institutions*.

The UGC implements the Universities with Potential for Excellence scheme, which dates from the *Ninth Five-Year Plan*; by 2014, 15 universities were receiving funding under this scheme and the UGC was making a fresh call for proposals to extend this opportunity to 10 more hopefuls, including private universities.

The UGC runs the Faculty Research Promotion Programme to reinvigorate basic research in the university sector, including in medical and engineering sciences. This programme provides three types of support: a research grant for entry-level faculty and for mid-career faculty and a fellowship for senior faculty nearing retirement whose proven track record argues in favour of keeping them on staff to mentor younger faculty.

The Department of Science and Technology (DST) contributes to the cost of research, staffing costs, equipment purchase and so on, through its programme for the Promotion of University Research and Scientific Excellence (PURSE), which has provided 44 universities with research grants over the past decade on the basis of their publication record.

The DST administers the Fund for the Improvement of Science and Technology Infrastructure in Higher Educational Institutions (FIST), which dates from 2001 and supported 1 800 departments and institutions between 2010 and 2013.

Since 2009, the DST has improved research infrastructure at six of India's universities for women, via the Consolidation of University Research for Innovation and Excellence (CURIE) programme. The second phase of the programme got under way in 2012.

The DST introduced the Innovation in Science Pursuit for Inspired Research (INSPIRE) programme in 2009 to stimulate a vocation for science. INSPIRE runs science camps and presents awards to 10–15 year-olds and internships to 16–17 year-olds. By 2013, it had also awarded 28 000 scholarships for undergraduate studies in the sciences, 3 300 fellowships to complete a PhD and 378 faculty awards to researchers under the age of 32, 30% of which went to the diaspora returning home to India to take up research positions.

The DST programme for Intensification of Research in High Priority Areas (IRHPA) was launched during the *Sixth Five-Year Plan*. It has set up core groups, centres of excellence and national facilities in frontline and emerging fields of science and engineering, such as neurobiology, solid state chemistry, nanomaterials, materials science, surface science, plasma physics or macromolecular crystallography.

Institutions receiving funding from the Department of Biotechnology and the Department of Science and Technology are obliged to set up an institutional repository for articles written by their staff; in turn, the Ministry of Science and Technology has undertaken to set up a central harvester linking each institutional repository.

Source: Lok Sabha (parliament), answer by Minister of Human Resource Development to question number 159, 7 July 2014; DST (2014); government website

CONCLUSION

Incentives have failed to create a broad innovation culture

From the foregoing, we can see that India's national innovation system faces several challenges. In particular, there is a need to:

- spread responsibility for attaining a GERD/GDP ratio of 2% by 2018 between the government and business enterprise sectors: the government should use this opportunity to raise its own share of GERD to about 1% of GDP by investing more heavily in university research, in particular, which currently performs just 4% of R&D, in order to enable universities to fulfil their role better as generators of new knowledge and providers of quality education;
- improve the training and density of scientists and engineers engaged in R&D: in recent years, the government has multiplied the number of institutions of higher education and developed a vast array of programmes to improve the quality of academic research; this is already producing results but more needs to be done to adapt curricula to market needs and to create a research culture at universities; none of the new universities established since 2010 is a designated 'innovation university,' for instance, despite the declared intention of creating 14 such universities in the *Eleventh Five-Year Plan* (2007–2012);
- initiate a government assessment of the effectiveness of tax incentives for R&D: despite India having one of the most generous tax regimes for R&D in the world, this has not resulted in the spread of an innovation culture across firms and industries;
- orient a greater share of government research grants towards the business sector: currently, most grants target the public research system, which is divorced from manufacturing; there are no large research grants which target the business enterprise sector to develop specific technologies, with the notable exception of the pharmaceutical industry; the Technology Development Board, for instance, has been disbursing more subsidized loans than grants. In this regard, the Science and Engineering Research Board set up in 2010 to feed research grants into the wider science system is a step in the right direction, as is the scheme for the Intensification of Research in High Priority Areas;
- support the emergence of technology-based enterprises by giving this type of SME greater access to venture capital; although there has been a venture capital industry in India since the late 1980s, its role has remained restricted of late to providing mainly private equity. In this regard, it is promising that the union government's budget for 2014–2015 proposes setting up a fund of Rs 100 billion (*circa* US$ 1.3 billion) to catalyse private equity, quasi equity, soft loans and other risk capital for start-ups;
- link technological capabilities in pharmaceutical and satellite technologies to the provision of services in health and education to the average Indian citizen: up until now, there has been little research on neglected tropical diseases and there has been a somewhat stultified use of satellite technologies to bring educational services to remote areas.

The biggest challenge of all for Indian policy-makers will be to tackle each of the aforementioned imperatives within a reasonable period of time.

KEY TARGETS FOR INDIA

- Raise GERD from 0.8% (2011) to 2.0% of GDP by 2018, half of which is to come from the private sector;
- Turn India into a global hub for nanotechnology by 2017;
- Raise the share of manufacturing from 15% (2011) to about 25% of GDP by 2022;
- Raise the share of high-tech products (aerospace, pharmaceuticals, chemicals, electronics and telecommunications) among manufactured products from 1% to at least 5% by 2022;
- Raise the share of high-tech goods among manufactured exports (currently 7%) by 2022;
- Install 100 gigawatts of solar energy across India by 2022.

REFERENCES

Brinton, T. J. *et al.* (2013) Outcomes from a postgraduate biomedical technology innovation training program: the first 12 years of Stanford Bio Design. *Annals of Biomedical Engineering*, 41(9): pp. 1 803–1 810.

Committee on Agriculture (2012) *Cultivation of Genetically Modified Food Crops: Prospects and Effects.* Lok Sabha Secretariat: New Delhi.

DHE (2014) *Annual Report 2013–2014.* Department of Higher Education, Ministry of Human Resources Development: New Delhi.

DHE (2012) *Annual Report 2011–2012.* Department of Higher Education, Ministry of Human Resources Development: New Delhi.

DST (2014) *Annual Report 2013–2014*. Department of Science and Technology: New Delhi.

DST (2013) *Research and Development Statistics 2011–2012*. National Science and Technology Information Management System. Department of Science and Technology: New Delhi.

DST (2009) *Research and Development Statistics 2007–2008*. National Science and Technology Information Management System. Department of Science and Technology: New Delhi.

Gruere, G. and Y. Sun (2012) *Measuring the Contribution of Bt Cotton Adoption to India's Cotton Yields Leap.* International Food Policy Research Institute Discussion Paper 01170.

Heller, K. Emont, J. and L. Swamy (2015) India's green bond: a bright example of innovative clean energy financing. US Natural Resources Defense Council. *Switchboard*, staff blog of Ansali Jaiswal, 8 January.

Jishnu, M. J. (2014) Agricultural research in India: an analysis of its performance. Unpublished MA project report. Centre for Development Studies: Trivandrum.

Mani, S. (2014) Innovation: the world's most generous tax regime. In: B. Jalan and P. Balakrishnan (eds) *Politics Trumps Economics: the Interface of Economics and Politics in Contemporary India*. Rupa: New Delhi, pp. 155–169.

Mani, S. (2002) *Government, Innovation and Technology Policy, an International Comparative Analysis.* Edward Elgar: Cheltenham (UK) and Northampton, Mass. (USA).

Mani, S. (2012) High skilled migration and remittances: India's experience since economic liberalization. In: K. Pushpangadan and V. N. Balasubramanyam (eds) *Growth, Development and Diversity, India's Record since liberalization.* Oxford University Press: New Delhi, pp. 181–209.

Mani, S. and R. R. Nelson (eds) (2013) *TRIPS compliance, National Patent Regimes and Innovation, Evidence and Experience from Developing Countries*. Edward Elgar: Cheltenham (UK) and Northampton, Mass. (USA).

Mukherjee, A. (2013) *The Service Sector in India*. Asian Development Bank Economic Working Paper Series no. 352.

NSB (2014) *Science and Engineering Indicators 2014*. National Science Board, National Science Foundation (NSB 14-01): Arlington Virginia, USA.

Pal, S. and D. Byerlee (2006) The funding and organization of agricultural research in India: evolution and emerging policy issues. In: P.G. Pardey, J.M. Alston and R.R. Piggott (eds) *Agricultural R&D Policy in the Developing World*. International Food Policy Research Institute: Washington, DC, USA, pp. 155–193.

Palanisami, K. *et al.* (2013) Doing different things or doing it differently? Rice intensification practices in 13 states of India. *Economic and Political Weekly,* 46(8): pp. 51–58.

Project on Emerging Nanotechnologies (2014) *Consumer Products Inventory*: www.nanotechproject.org/cpi

Radjou, N.; Jaideep, P. and S. Ahuja (2012) *Jugaad Innovation: Think Frugal, Be Flexible, Generate Breakthrough Growth*. Jossey–Bass: London.

Ramani, S. V.; Chowdhury, N.; Coronini, R. and S. E. Reid (2014) On India's plunge into nanotechnology: what are good ways to catch-up? In: S. V. Ramani (ed) *Nanotechnology and Development: What's in it for Emerging Countries?* Cambridge University Press: New Delhi.

Sanyal, S. (2014) *A New Beginning for India's Economy*. Blog of 20 August. World Economic Forum.

Science Advisory Council to the Prime Minister (2013) *Science in India, a decade of Achievements and Rising Aspirations*. Department of Science and Technology: New Delhi.

UNDP (2014) *Humanity Divided, Confronting Inequality in Developing Countries*. United Nations Development Programme.

VIB (2013) *Bt Cotton in India: a Success Story for the Environment and Local Welfare.* Flemish Institute for Biotechnology (VIB): Belgium.

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The 'new normal' [of slower but steadier economic growth] highlights the urgency for China to transform its economic development model from one that is labour-, investment-, energy- and resource-intensive to one that is increasingly dependent upon technology and innovation.

Cong Cao

A high-speed train in Shanghai station in June 2013; the latest trains can clock a speed of up to 487 km/h in test conditions.
Photo © Anil Bolukbas/iStockPhoto

23 · China

Cong Cao

INTRODUCTION

The 'new normal'

China's socio-economic situation has evolved since 2009[1] in a climate of uncertainty caused first by the global financial crisis of 2008–2009 then by the domestic transtion in political leadership in 2012. In the immediate aftermath of the US subprime mortgage crisis in 2008, the Chinese government took swift action to limit the shockwaves by injecting RMB 4 trillion (US$ 576 billion) into the economy. Much of this investment targeted infrustructure projects such as airports, motorways and railroads. Combined with rapid urbanization, this spending spree on infrastructure drove up the production of steel, cement, glass and other 'building-block' industries, prompting concern at the potential for a hard landing. The construction boom further damaged China's environment. For example, outdoor air pollution alone contributed to 1.2 million premature deaths in China in 2010, nearly 40% of the world total (Lozano *et al.,* 2012). When China hosted the Asia–Pacific Economic Cooperation (APEC) summit in mid-November 2014, factories, offices and schools in Beijing and surrounding areas were all closed for several days to ensure blue skies over the capital for the duration of the summit.

The post-2008 economic stimulus package was also compromised by the failure of the government's policy to support the development of so-called strategic emerging industries. Some of these industries were export-oriented, including manufacturers of wind turbines and photovoltaic panels. They were hard hit by the slump in global demand during the global financial crisis but also by the anti-dumping and anti-subsidy measures introduced by some Western countries. The manufacturing glut that ensued bankrupted some of the global leaders in solar panel manufacturing, such as Suntech Power and LDK Solar, which were already ailing by the time the Chinese government cut back on its own subsidies in order to rationalize the market.

Despite these hiccups, China emerged triumphantly from the crisis, maintaining average annual growth of about 9% between 2008 and 2013. In terms of GDP, China overtook Japan in 2010 to become the world's second-largest economy and is now catching up with the USA. When it comes to GDP per capita, however, China remains an upper middle-income country. In a reflection of its growing role as an economic superpower, China is currently spearheading three major multilateral initiatives:

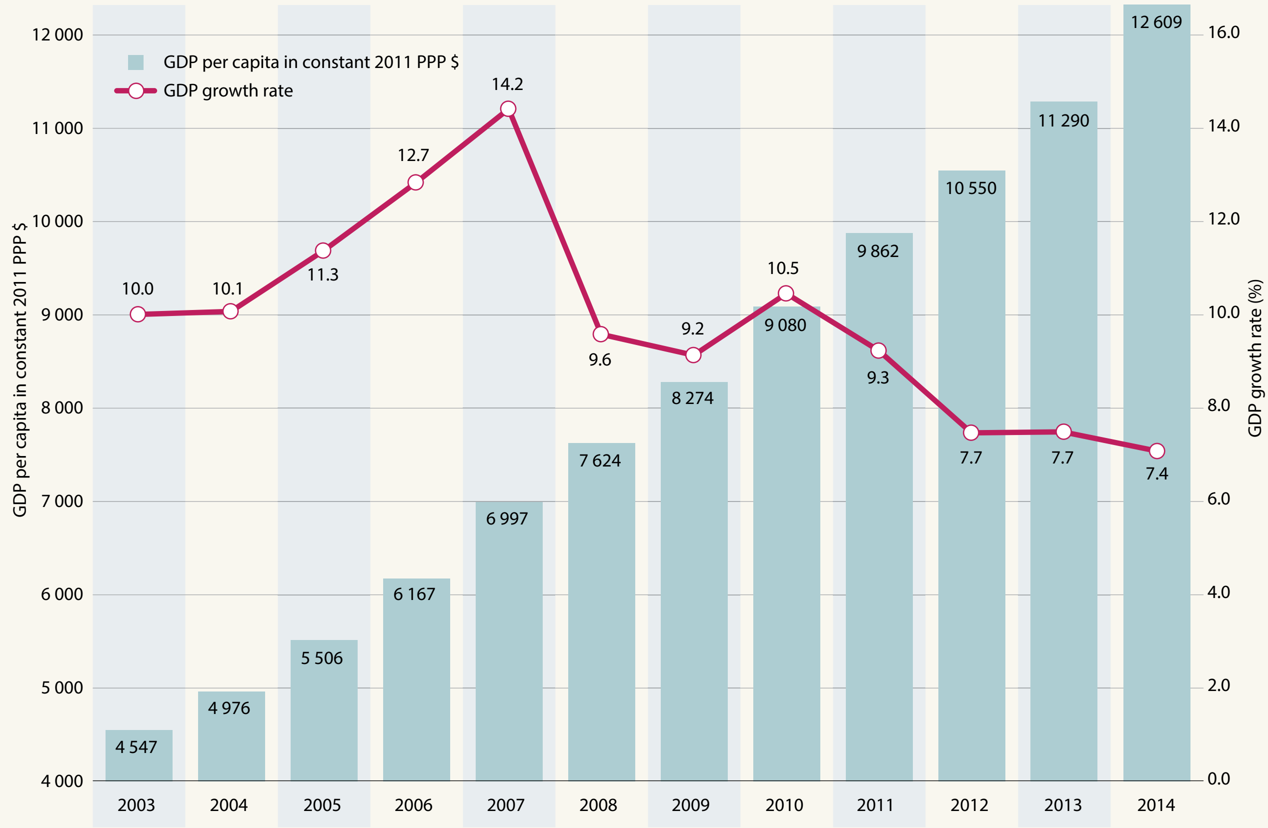
- the creation of the Asian Infrastructure Investment Bank to finance infrastructure projects, which will be based in Beijing and should be operational by the end of 2015; more than 50 countries have already expressed interest in joining, including France, Germany, the Republic of Korea and the UK;
- the approval by Brazil, the Russian Federation, India, China and South Africa (BRICS) in July 2014 of the New Development Bank (or BRICS Development Bank), with a primary focus on lending for infrastructure projects; it will be based in Shanghai; and
- the creation of an Asia–Pacific Free Trade Area, which, according to China's vision, would override existing bilateral and multilateral free trade agreements in the region; in November 2014, the APEC summit endorsed the Beijing Roadmap for completing a feasibility study by late 2016.

Meanwhile, China initiated a change in its political leadership in November 2012, when Xi Jinping acceded to the post of General Secretary of the Central Committee of the Chinese Communist Party (CCP) at the 18th CCP National Congress. At the first session of the 12th National People's Congress, held in March 2013, Xi Jinping and Li Keqiang took over the state presidency and premiership respectively. The Xi–Li administration inherited the legacy of an economy which had been growing at almost 10% on average for the past decade, as China vigorously pursued its open-door policy initiated by reformist leader Deng Xiaoping back in 1978. Today, China's economy seems to have reached a plateau, or a 'new normal' (*xin changtai*), characterized by steadier, albeit slower growth: GDP progressed by just 7.4% in 2014, the lowest rate in 24 years (Figure 23.1). China is gradually losing its status as 'the world's factory,' as rising costs and stringent environmental regulations make its manufacturing sector less competitive than in countries paying lower wages and offering less environmental protection. The 'new normal' therefore also highlights the urgency for China to transform its economic development model from one that is labour-, investment-, energy-, and resource-intensive into one that is increasingly dependent upon technology and innovation. The 'smart cities' initiative is one example of how the Chinese leadership is tackling this challenge (Box 23.1).

China faces other challenges which range from inclusive, harmonious and green development to an ageing society and the 'middle income trap.' All these call for the acceleration of the reform, which seems to have been delayed up until now by China's response to the global financial crisis. That may be about to change. The new leadership has put forward an ambitious and comprehensive reform agenda, in addition to launching an unprecedented anti-corruption campaign targeting some high-ranking government officials.

1. Total debt in China stood at about 210% of GDP by the end of 2014: household debt accounted for 34% of GDP, government debt 57% and corporate debt, including both loans and bonds, for 119%, according to the UNESCO Institute for Statistics.

Figure 23.1: **Trends in GDP per capita and GDP growth in China, 2003–2014**



Source: World Bank's World Development Indicators, March 2015

Box 23.1: **China's smart cities**

The 'smart city' takes its origin from the concept of 'smart planet' created by IBM. Today, the term 'smart cities' refers to futuristic urban centres where the use of information technology and data analysis improves infrastructure and public services so as to engage more effectively and actively with citizens. The development of smart cities takes advantage of synergic innovation around existing technologies cutting across many industries – transportation and utility infrastructure, telecommunications and wireless networks, electronic equipment and software applications, as well as emerging technologies such as ubiquitous computing (or the internet of things), cloud computing and 'big data' analytics. In a word, smart cities represent a new trend of industrialization, urbanization and informatization.

China is embracing the idea of smart cities to tackle challenges in government services, transportation, energy, environment, health care, public safety, food safety and logistics.

The *Twelfth Five-Year Plan* (2011–2015) specifically calls for the development of smart city technologies to be encouraged, thus stimulating the initiation of programmes and industrial alliances, such as the:

- China Strategic Alliance of Smart City Industrial Technology Innovation, managed by the Ministry of Science and Technology (MoST) since 2012;
- China Smart City Industry Alliance, managed by the Ministry of Industry and Information Technology (MoIIT) since 2013; and the
- Smart City Development Alliance, managed by the National Development and Reform Commission (NDRC) since 2014.

The most far-reaching effort has been led by the Ministry of Housing and Urban and Rural Development (MoHURD). By 2013, it had selected 193 cities and economic development zones to be official smart city pilot sites. The pilot cities are eligible for funding from a RMB 1 billion (US$ 16 billion) investment fund sponsored by the China Development Bank. In 2014, MoIIT also announced a RMB 50 billion fund to invest in smart city research and projects. Investment from local government and private sources has also been growing fast. It is estimated that total investment over the *Twelfth Five-Year Plan* period will reach some RMB 1.6 trillion (US$ 256 billion).

TRENDS IN R&D

The world's biggest R&D spender by 2019?

Over the past decade, China has been following a sharp uphill trajectory in science, technology and innovation (STI), at least in quantitative terms (Figures 23.2 and 23.3). The country has been spending a growing share of its burgeoning GDP on research and development (R&D). Gross domestic expenditure on R&D (GERD) stood at 2.08% in 2013, surpassing that of the 28-member European Union (EU), which managed an average intensity of 2.02% in 2013 (see Chapter 9). China's indicator nudged farther ahead to 2.09% of GDP in 2014. According to the biennial *Science, Technology and Industry Outlook 2014* (OECD, 2014), China will outpace the USA as the world's leading R&D spender by around 2019, reaching another important milestone in its endeavour to become an innovation-oriented nation by 2020. The policy focus on experimental development over the past 20 years, to the detriment of applied research and, above all, basic research, has resulted in enterprises contributing more than three-quarters of GERD. Since 2004, the bias in favour of experimental development has become even more pronounced (Figure 23.4).

China's S&T talent has been growing, with institutions of higher education turning out an increasing number of well-prepared graduates, especially in science and engineering. In 2013, the number of postgraduate students reached 1.85 million, on top of the 25.5 million undergraduates (Table 23.1). The number of researchers in China is unequivocally the world's highest: 1.48 million full-time equivalents (FTE) in 2013.

China's State Intellectual Property Office received more than half a million applications for invention patents in 2011, making it the world's largest patent office (Figure 23.5). There has also been a steady increase in the number of international papers by Chinese scientists in journals catalogued in the *Science Citation Index*. By 2014, China ranked second in the world after the USA, in terms of volume (Figure 23.6).

Some outstanding achievements

Chinese scientists and engineers have chalked up some outstanding achievements since 2011. In basic research, frontier discoveries include the quantum anomalous Hall effect, high-temperature superconductivity in iron-based materials, a new kind of neutrino oscillation, a method of inducing pluripotent stem cells and the crystal structure of the human glucose transporter GLUT1. In the area of strategic high technology, the Shenzhou space programme has pursued inhabited space flights. The first Chinese spacewalk dates from 2008. In 2012, the Tiangong-1 space module docked in space for the first time, allowing the first woman *taikongnaut* to go for a spacewalk. In December 2013, Chang'e 3 became the first spacecraft to land on the Moon since the Soviet Union's craft in 1976. China has also made breakthroughs in deep-ground drilling and supercomputing. China's first large passenger aircraft, the ARJ21-700 with a capacity for 95 passengers, was certified by the national Civil Aviation Administration on 30 December 2014.

Given such an attraction, a growing number of Chinese citizens will be clamouring for their city to climb on the 'smart city' bandwagon.

In early 2014, the ministries involved in the smart city initiative joined forces with the Standardization Administration of China to create working groups entrusted with managing and standardizing smart city development.

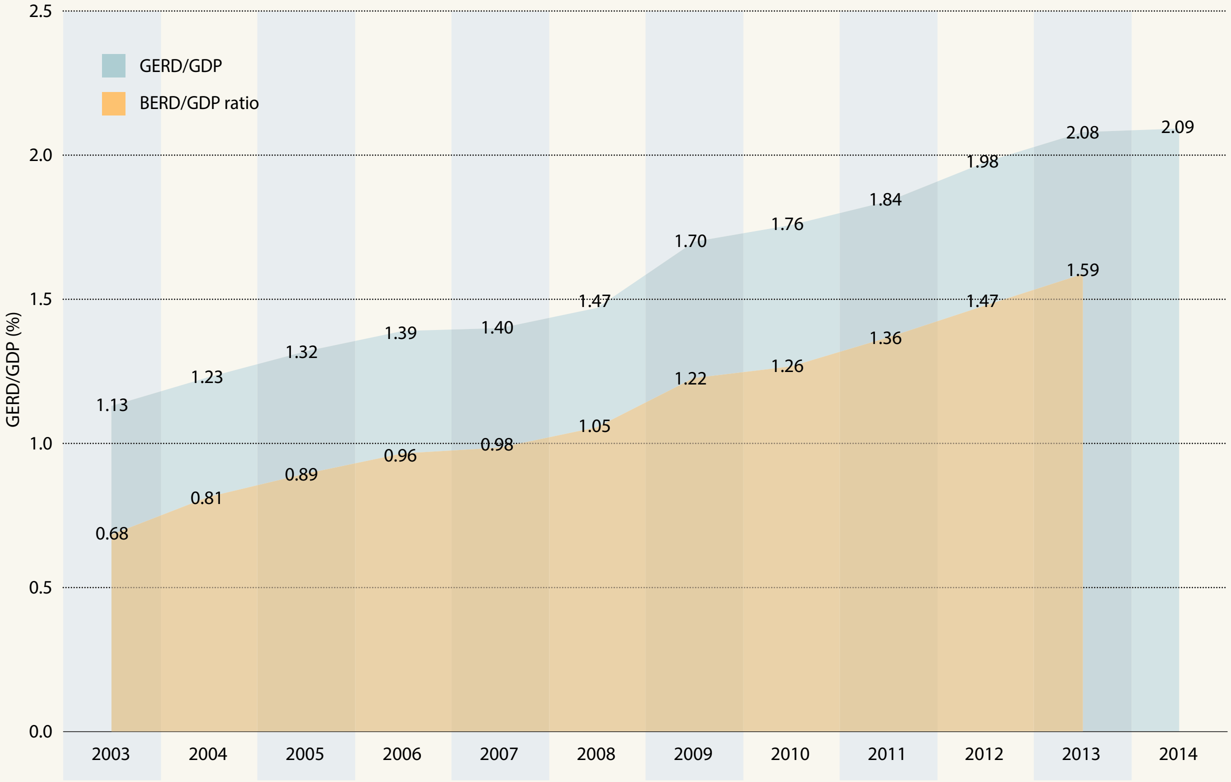
Apparently, it is the smart city boom which drove eight government agencies to issue a joint guide in August 2014, in order to improve co-ordination and communication between industrial participants and between industry and government agencies, entitled *Guidance on Promoting the Healthy Development of Smart Cities*. The document proposed establishing a number of smart cities with distinctive characteristics by 2020 to lead the development of smart cities across the country. The eight government agencies were the NDRC and seven ministries: MoIIT, MoST, Public Security, Finance, Land Resources, MoHURD and Transportation.

Companies such as IBM have not only used the smart city concept as their marketing strategy but also seized upon the opportunity to develop their businesses in China. As early as 2009, IBM launched a 'smart city' programme in the northeastern city of Shenyang in Liaoning province, hoping to showcase its strengths. It has also worked with Shanghai, Guangzhou, Wuhan, Nanjing, Wuxi and other cities on their own smart city initiatives. In 2013, IBM set up its first Smart Cities Institute in Beijing as an open platform for experts from the company, as well as its partners, clients, universities and other research institutions to work on joint projects related to smart water resources, smart transportation, smart energy and smart new cities.

Chinese firms that have also been adept at mastering technologies and shaking up markets include Huawei and ZTE, both telecommunications equipment manufacturers, as well as China's two electric grid companies, State Grid and Southern Grid.

Source: www.chinabusinessreview.com

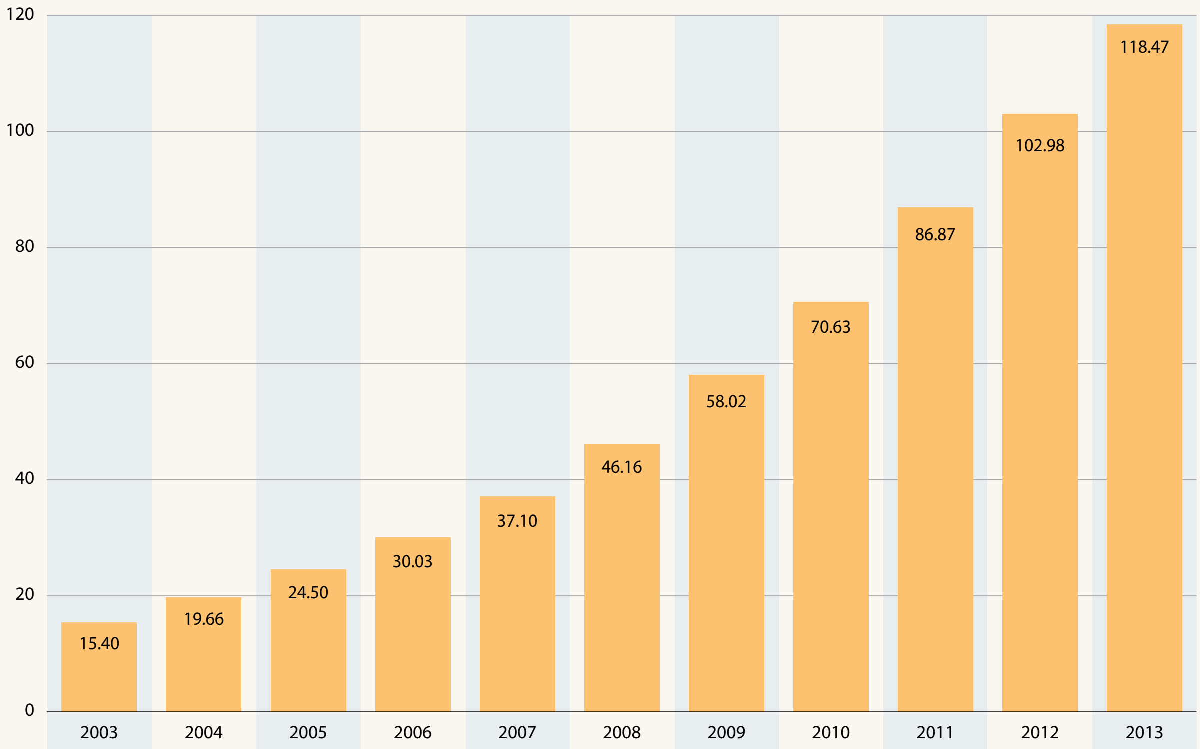
Figure 23.2: **Chinese GERD/GDP ratio and BERD/GDP ratio, 2003–2014 (%)**



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

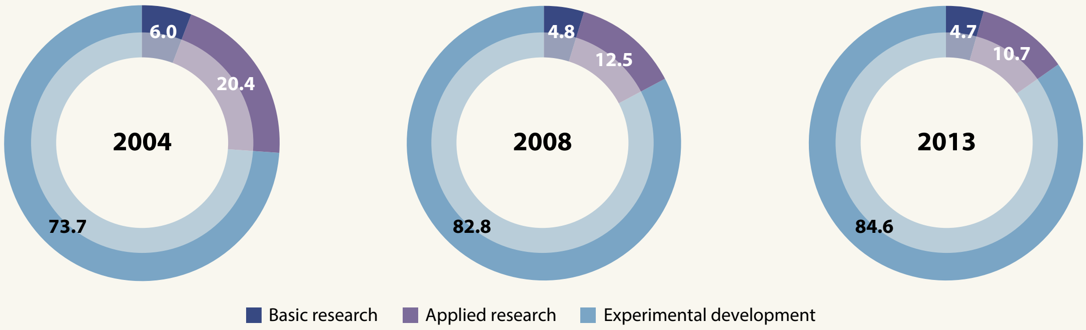
Figure 23.3: **Growth in Chinese GERD, 2003 –2013**

In RMB 10 billions



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

Figure 23.4: **GERD in China by type of research, 2004, 2008 and 2013 (%)**



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

Table 23.1: **Trends in Chinese human resources in S&T, 2003–2013**

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
FTE research personnel ('000s)	1 095	1 153	1 365	1 503	1 736	1 965	2 291	2 554	2 883	3 247	3 533
FTE research personnel per million inhabitants	847	887	1 044	1 143	1 314	1 480	1 717	1 905	2 140	2 398	2 596
Graduate student enrolment ('000s)	651	820	979	1 105	1 195	1 283	1 405	1 538	1 646	1 720	1 794
Graduate student enrolment per million inhabitants	504	631	749	841	904	966	1 053	1 147	1 222	1 270	1 318
Undergraduate student enrolment (millions)	11.09	13.33	15.62	17.39	18.85	20.21	21.45	22.32	23.08	23.91	24.68
Undergraduate student enrolment per million inhabitants	8 582	10 255	11 946	13 230	14 266	15 218	16 073	16 645	17 130	17 658	18 137

Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

A number of major gaps in technology and equipment have been filled in recent years, especially in information and communication technologies (ICTs),[2] energy, environmental protection, advanced manufacturing, biotechnology and other strategic emerging industries for China.[3] Large facilities such as the Beijing Electron-Positron Collider (est. 1991), Shanghai Synchrotron Radiation Facility (est. 2009) and Daya Bay neutrino oscillation facility have not only yielded significant findings in basic science but also provided opportunities for international collaboration. The Daya Bay Neutrino Experiment, for example, which began collecting data in 2011, is being led by Chinese and American scientists, with participants from the Russian Federation and other countries.

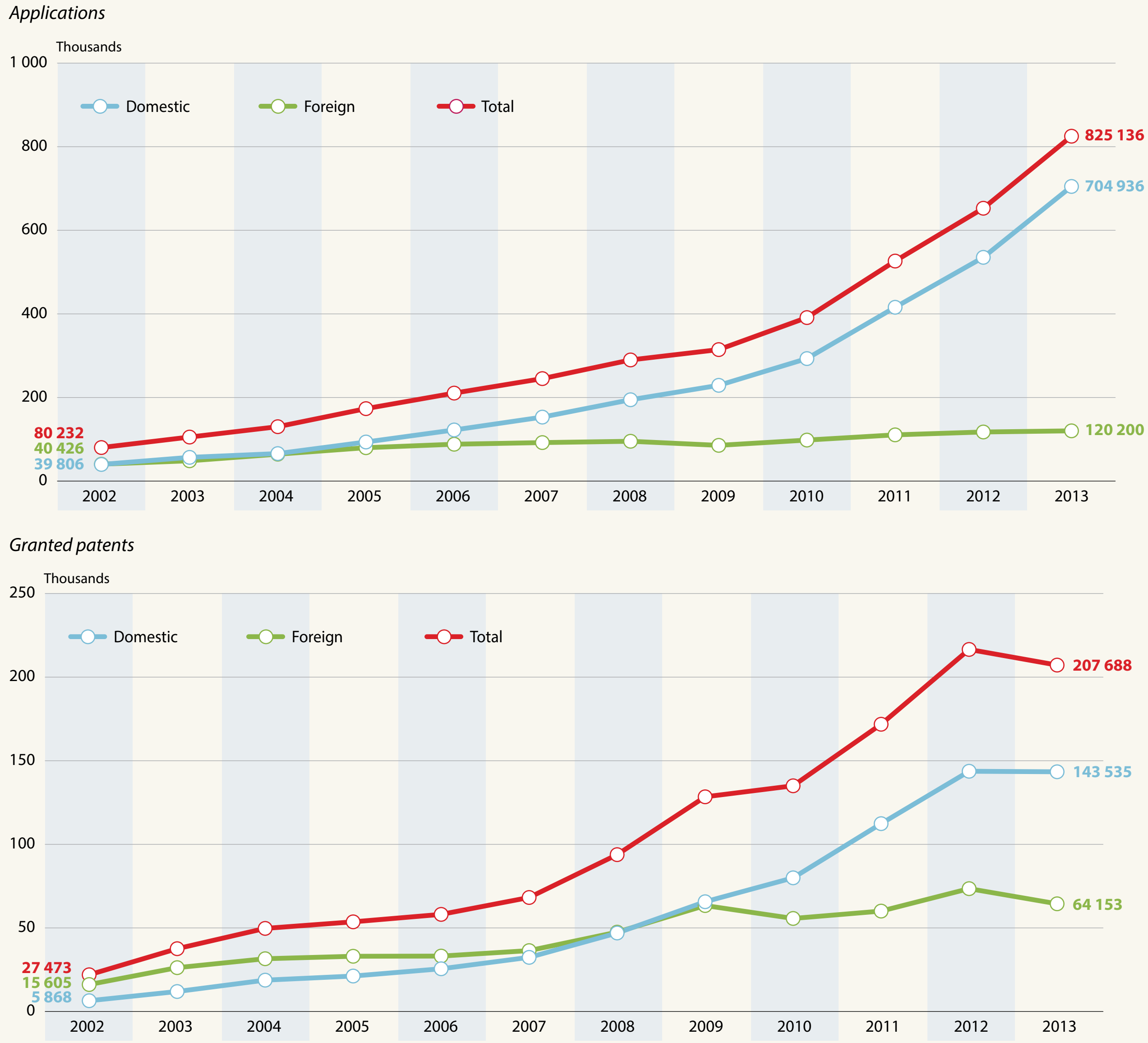
A leap forward in medical sciences

China has made leaps and bounds in medical sciences in the past decade. Publications in this field more than tripled between 2008 and 2014 from 8 700 to 29 295, according to the Web of Science. This progression has been much faster than in China's traditional strengths of materials science, chemistry and physics. According to the Institute of Scientific and Technical Information of China, which is affiliated with the Ministry of Science and Technology (MoST), China contributed about one-quarter of all articles published in materials science and chemistry and 17% of those published in physics between 2004 and 2014 but just 8.7% of those in molecular biology and genetics. This nevertheless represents a steep rise from just 1.4% of the world share of publications in molecular biology and genetics over 1999–2003. In the early 1950s, Chinese research in genetics came to a standstill after the country officially adopted Lysenkoism, a doctrine developed by Russian peasant plant-breeder Trofim Denisovich Lysenko (1898–1976) which had already stalled genetic research in the Soviet Union. Essentially, Lysenkoism dictated that we are what we learn. This environmentalism denied the role played by genetic inheritance in evolution. Although Lysenkoism was discarded in the late 1950s, it has taken Chinese geneticists decades to catch up (UNESCO, 2012). China's participation in the Human Genome Project at the turn of the century was a turning point. More recently, China has thrown its support behind the Human Variome Project, an international endeavour to catalogue human genetic variation worldwide, in order to improve diagnosis and treatment, with support

2. 649 million Chinese inhabitants had access to internet by the end of 2014.

3. China defines strategic emerging industries as: energy-saving and environment-friendly technologies, new generation ICTs, biotechnology, advanced manufacturing, new energy, new materials and automobiles powered by new energy sources.

Figure 23.5: **Applications and patents granted to Chinese and foreign inventors, 2002–2013**



Source: National Bureau of Statistics and Ministry of Science and Technology (various years) *China Statistical Yearbook on Science and Technology*

from UNESCO's International Basic Sciences Programme. In 2015, the Beijing China Health Huayang Institute of Gene Technology committed *circa* US$ 300 million to the Human Variome Project; the funds will be used over the next ten years to build 5 000 new gene- and disease-specific databases and to establish the Chinese node of the Human Variome Project.

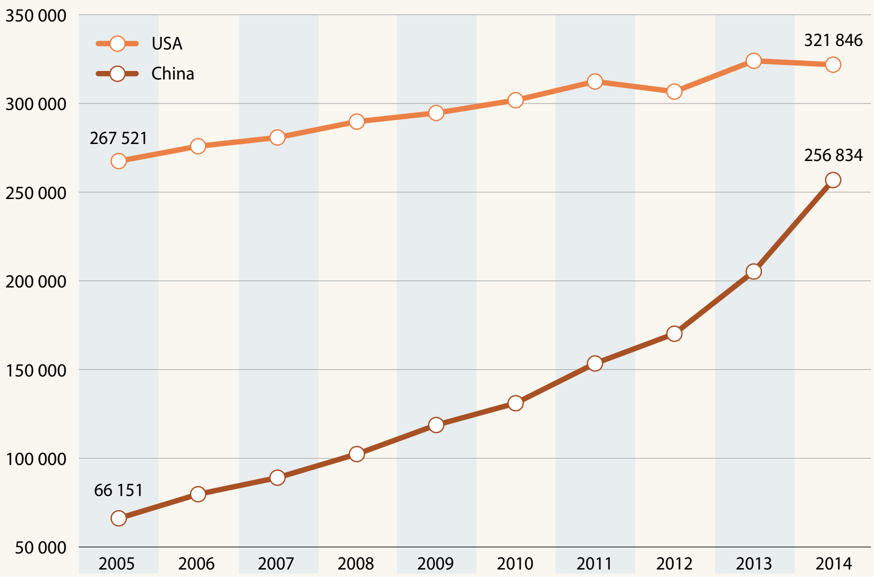
Two new regional centres for training and research

Other opportunities for international collaboration have arisen from the establishment of two regional centres for research and training since 2011, which function under the auspices of UNESCO:

- the Regional Training and Research Centre on Ocean Dynamics and Climate was launched on 9 June 2011 in Qingdao City. It is hosted by the First Institute of Oceanography, part of the State Oceanic Administration, and trains young scientists from Asian developing countries, in particular, at no cost to the beneficiary;
- the International Research and Training Centre for Science and Technology Strategy was inaugurated in Beijing in September 2012. It designs and conducts international co-operative research and training programmes in such areas as S&T indicators and statistical analysis, technology foresight and road-mapping, financing policies for innovation, the development of small and medium-sized enterprises, strategies for addressing climate change and sustainable development, etc.

Figure 23.6: **Scientific publication trends in China, 2005–2014**

China could become world's largest scientific publisher by 2016



0.98

Average citation rate for Chinese scientific publications, 2008–2012; the OECD average is 1.08; the G20 average is 1.02

10.0%

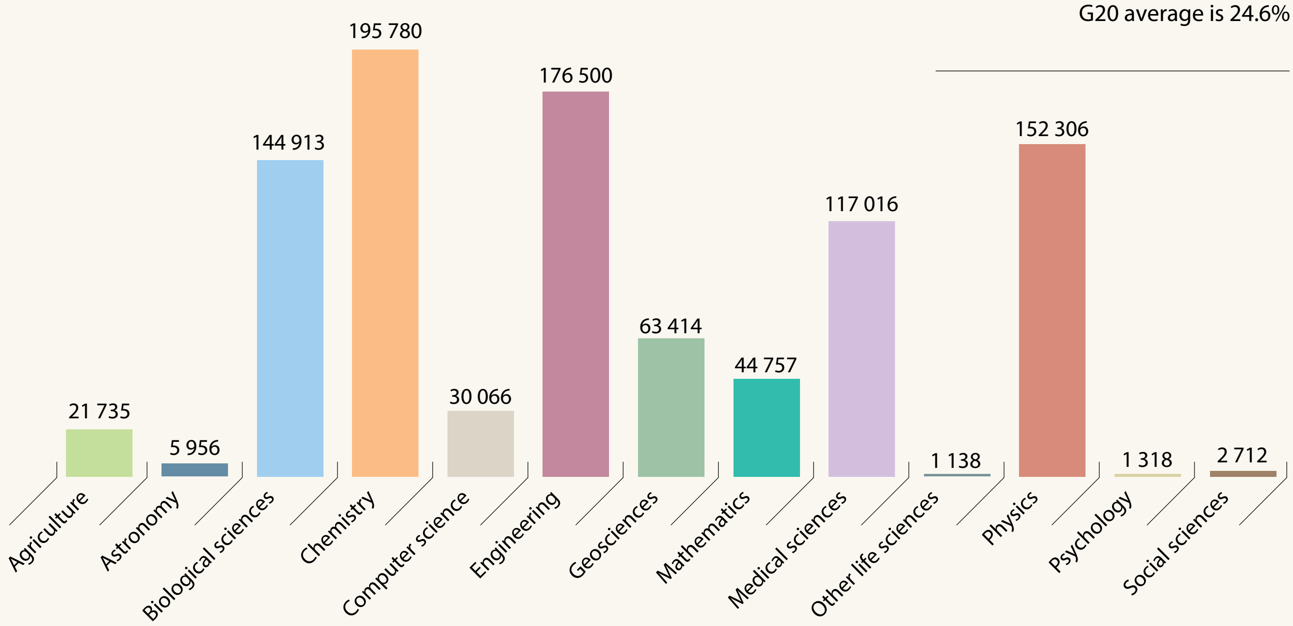
Share of Chinese papers among 10% most cited, 2008–2012; the OECD average is 11.1%; the G20 average is 10.2%

24.4%

Share of Chinese papers with foreign co-authors, 2008–2014; the OECD average is 29.4%; the G20 average is 24.6%

Chemistry, engineering and physics dominate Chinese science

Cumulative totals by field 2008–2014



Note: The totals exclude 180 271 unclassified publications.

The USA outstrips all others as China's main partner

Main foreign partners 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
China	USA (119 594)	Japan (26 053)	UK (25 151)	Australia (21 058)	Canada (19 522)

Note: The statistics for China do not include Hong Kong SAR or Macao SAR.

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded, data treatment by Science–Metrix

TRENDS IN STI GOVERNANCE

Reform driven by engineers turned politicians

China's astonishing progress in STI can be attributed to a series of policies adopted during the reformist open-door era since 1978, from 'rejuvenating the nation with science, technology and education' (*kejiao xingguo*), in 1995, 'empowering the nation with talent' (*rencai qiangguo*), in 2001, and 'building up an endogenous innovation capability' (*zizhu chuangxin nengli*) to 'turning China into an innovation-oriented nation' (*chuangxin guojia*) in 2006, a strategy ensconced in the *National Medium and Long-term Plan for the Development of Science and Technology (2006–2020)*. The Chinese power structure in the 1980s and 1990s could be described as an alliance between career bureaucrats and technocrats; the bureaucrats needed the technocrats to modernize and develop the economy, whereas the technocrats needed the bureaucrats to advance their political careers. Following Deng's death in 1997, Jiang Zemin became China's 'top technocrat' and instigated a fully-fledged technocracy (Yoon, 2007). Given their training at the nation's top science and engineering schools, China's governing political elite was naturally inclined to favour policies that promoted advances in science and technology (Suttmeier, 2007). Only in its current top leadership did China start to see the rise of social scientists: Xi Jinping holds a PhD in Law from Tsinghua University and Li Keqiang obtained his PhD in Economics from Beijing University. However, the change in educational background of the current leadership does not mean that attitudes towards science and technology have changed among these top leaders.

In July 2013, soon after being made General Secretary of the Chinese Communist Party's (CCP's) Central Committee and State President, Xi Jinping paid a visit to the Chinese Academy of Sciences (CAS), the nation's leading institution for science and research. His articulation of the problems facing the development of science and technology in China was distilled into 'four mismatches' (*sige buxiang shiying*): mismatches between the level of technological development and the requirements of socio-economic development; between the S&T system and the requirements of science and technology for the system to develop rapidly; between the distribution of S&T disciplines and the requirements of science and technology for these disciplines to develop; and between existing S&T personnel and the requirements of the nation in terms of talent. Xi then urged CAS to be 'a pioneer in four areas' (*sige shuaixian*): in leapfrogging to the frontier of scientific research, in enhancing the nation's innovative talent pool, in establishing the nation's high-level think tank in science and technology and in becoming a world-class research institution.

China's political leadership is also enthusiastic about broadening its knowledge. This is illustrated by the fact that, since 2002, the Politburo of the CCP's Central Committee has held frequent group study sessions, to which leading Chinese scholars have been invited to lecture on subjects related to China's socio-economic development, including STI. The Xi–Li duo has pursued this tradition. In September 2013, the Politburo held a group study at Beijing's Zhongguancun Science Park, also known as China's 'Silicon Valley.' During this ninth group study session run by the new leadership – the first ever held outside the Communist Party's Zhongnanhai headquarters – members of the Politburo showed particular interest in new technologies such as three-dimensional printing, big data and cloud computing, nano-materials, biochips and quantum communications. While stressing the importance of science and technology in enhancing the nation's strength, in the speech he gave for the occasion, Xi Jinping indicated that China should focus on integrating innovation with socio-economic development, enhancing the capability for endogenous innovation, nurturing talent, constructing a favourable policy environment for innovation and continuing to open up and engage in international co-operation in science and technology. Calls from the leadership since 2013 for 'positive energy' (*zheng nengliang*) to prevail in all spheres of society, including the university sector, have raised concerns, however, that this new doctrine may inhibit the critical thinking which nurtures creativity and problem-solving research, if the evocation of problems comes to be assimilated with 'negative energy.'

The new leadership is focusing on weaving together the so-called 'two layers of skin' (*liang zhang pi*) of research and the economy, a long-lasting challenge for China's S&T system. The main topic of discussion at the seventh meeting of the Central Leading Group for Financial and Economic Affairs on 18 August 2014, chaired by Xi Jinping, was a draft innovation-driven development strategy which was formally released by the CCP Central Committee and State Council on 13 March 2015. This, in itself, reflects the importance that the leadership attaches to innovation for restructuring China's economic development model.

Enterprises still dependent on foreign core technologies

In fact, the attention being paid to STI at the moment by the political leadership stems from its dissatisfaction with the current performance of the domestic innovation system. There exists a mismatch between input and output (Simon, 2010). Despite a massive injection of funds (Figure 23.3), better-trained researchers and sophisticated equipment, Chinese scientists have yet to produce cutting-edge breakthroughs worthy of a Nobel Prize, including the returnees who are now firmly embedded in domestic research and innovation (Box 23.2). Few research results have been turned into innovative and competitive technology and products. The commercialization of public research results has been rendered difficult, if not impossible, by the fact that these results are considered public goods, thus disincentivizing researchers engaged in technology transfer. With few exceptions, Chinese enterprises still depend on foreign sources for core technologies. According to a World Bank study, China had a US$ 10 billion deficit in 2009 in its intellectual property balance of payments, based on royalties and license fees (Ghafele and Gibert, 2012).

These problems have forced China to put its ambition on hold of embarking on a truly innovation-driven development trajectory. Indeed, China's drive to become a global leader in STI is tied to its capacity to evolve towards a more efficient, effective and robust national innovation system. Upon closer examination, there is a lack of co-ordination between the various actors at the macro level, an unfair distribution of funding at the meso level and an inappropriate performance evaluation of research projects and programmes, individual scientists and institutions at the micro level. It would seem to be both urgent and inevitable to institute reforms across all three levels of the national innovation system (Cao *et al.*, 2013).

Reform has accelerated under the new leadership

The current reform of the country's science and technology system was initiated against such a backdrop. It got under way in early July 2012, when a National Conference on Science, Technology and Innovation was convened shortly before the transition in leadership. One key outcome of the conference was an official document, *Opinions on Deepening the Reform of the Science and Technology System and Accelerating the Construction of the National Innovation System*, released in September. Produced by the CCP's Central Committee and State Council, this document furthered implementation of the *National Medium- and Long-Term Plan for the Development of Science and Technology (2006–2020),* which was released in 2006.

It was also in September 2012 that a new State Leading Group of Science and Technology System Reform and Innovation System Construction convened its first meeting. Made up of representatives from 26 government agencies and headed by Liu Yandong, a member of the Central Committee Politburo and state councillor, the leading group is mandated to guide and co-ordinate the reform and the construction of China's national innovation system, in addition to discussing and approving key regulations. When the country's top leadership changed a few months later, Liu not only kept her party position but was also promoted to vice premier in the state apparatus, thereby ensuring continuity and confirming the importance attached to scientific affairs.

The reform of the S&T system has accelerated since the change in political leadership. In general, the reform conducted by the Xi–Li tandem is characterized by so-called 'top-level design' (*dingceng sheji*), or strategic considerations in formulating the guidelines, so as to ensure that the reform is comprehensive, co-ordinated and sustainable; a balanced and focused approach towards reform which takes into consideration the interests of the CCP and country; and a focus on overcoming institutional and structural barriers, not to mention deep-seated contradictions, while promoting co-ordinated innovation in economic, political, cultural, social and other institutions. Of course, the 'top-level design' has been more broadly exercised in the reforms under the Xi–Li administration. In particular, the reform of the S&T system has strong political backing, with Xi Jinping's aforementioned visit to CAS and the Politburo's Zhongguancun group study setting the course. On several occasions, Xi has taken time off from his busy schedule to preside over the presentation of reports by the relevant government agencies on progress with the reform and the innovation-driven development strategy. He has also been very hands-on when it comes to the reform of China's elite academician (*yuanshi*) system at CAS and the Chinese Academy of Engineering (CAE), the broader reform of CAS and that of funding mechanisms for the centrally financed national science and technology programmes (see p. 633).

A mid-term review of the *Medium- and Long-Term Plan*

In addition to the political leadership's concerns about the mismatch between the soar in R&D input and the relatively modest output in science and technology, coupled with the necessity of harnessing science and technology to restructuring China's economy, the desire for reform may have been spurred by the mid-term review of the *National Medium and Long-term Plan for the Development of Science and Technology (2006–2020)*. As we saw in the *UNESCO Science Report 2010*, the *Medium- and Long-term Plan* set several quantitative goals for China to achieve by 2020, including (Cao *et al.,* 2006):

- raising investment in R&D to 2.5% of GDP;
- raising the contribution of technological advances to economic growth to more than 60%;
- limiting China's dependence on imported technology to no more than 30%;
- becoming one of the top five countries in the world for the number of invention patents granted to its own citizens; and
- ensuring that Chinese-authored scientific papers figure among the world's most cited.

China is well on the way to reaching these quantitative goals. As we have seen, by 2014, GERD had reached 2.09% of GDP. Moreover, technological advances are already contributing more than 50% to economic growth: in 2013, Chinese inventors were granted some 143 000 invention patents and China had risen to fourth place worldwide for the number of citations of Chinese-authored scientific papers. China's dependence on foreign technology should drop to about 35% by 2015. Meanwhile, various government ministries have worked together to initiate policies designed to facilitate implementation of the *Medium- and Long-Term Plan*. These policies include providing innovative enterprises with tax incentives and other forms of financial support, prioritizing domestic high-tech enterprises for government procurement, encouraging assimilation and re-innovation based on imported technology, strengthening the protection of intellectual property rights, nurturing talent, enhancing education and science popularization and establishing the basic platform of S&T innovation (Liu, *et al.,* 2011).

This begs the question: if we look beyond the statistics, what impact has the *Medium- and Long-Term Plan* had on realizing China's ambition of becoming an innovation-oriented nation by 2020? The mid-term review of the *Medium- and Long-Term Plan's* implementation was approved by the State Council in November 2013. The Ministry of Science and Technology led this effort, assisted by a steering committee set up in conjunction with 22 government agencies, the Chinese Academy of Engineering having been commissioned to organize the review. The same 20 thematic groups which had conducted strategic research at the stage of drafting the *Medium- and Long-Term Plan* now consulted experts from CAS, CAE and the Chinese Academy of Social Sciences. Consultations at CAS alone involved more than 200 experts. Focus groups were constituted with personnel from innovative enterprises, multinational companies operating in China, R&D institutes, universities and other sectors. Attention was paid to measuring the progress made by the 16 mega-engineering programmes (Table 23.2), as well as cutting-edge basic research conducted in a number of key areas through mega-science programmes, the reform of the S&T system, the construction of an enterprise-centered national innovation system, the policies formulated to support implementation of the *Medium- and Long-Term Plan* and so on. Through expert interviews and consultations, as well as questionnaires, the review team also solicited the views of international experts and scholars on China's evolving capability for

Box 23.2: **Wooing the Chinese elite back home**

Since the introduction of the open-door policy, China has sent more than 3 million students overseas. Of these, about 1.5 million have returned (Figure 23.7). Among the returnees figure a growing number of seasoned entrepreneurs and professionals who have taken advantage of the vast opportunities created by China's rapid economic growth and the preferential policies implemented by the Chinese government to woo them.

Since the mid-1990s, high-profile programmes have been rolled out by the Ministry of Education (Cheung Kong Scholar Programme), the Chinese Academy of Sciences (One Hundred Talents Programme) and other central and local government agencies. These talent-focused programmes have dangled extremely generous incentives, resources and honours before potential recruits. They have targeted scientific pioneers, leaders in key technologies and corporate managers from high-tech industries but also – especially during the global financial crisis – professionals from consulting and the financial and legal worlds. However, these programmes have failed to persuade expatriate Chinese occupying the top jobs to return home.

Unhappy about the overall progress in STI and higher education despite an avalanche of funds, China's political leadership has attributed the problem to the lack of talent of the calibre of the father of China's space technology, Qian Xuesen, or the founder of geomechanics, Li Siguang, or of nuclear physicist Deng Jiaxian. In late 2008, the Department of Organization of the CCP's Central Committee, which appoints and evaluates senior officials at the provincial and ministerial levels, added the title of 'headhunter' to its curriculum vitae by initiating the Thousand Talents Programme *(qianren jihua)*.

In essence, the Thousand Talents Programme aims to spend 5–10 years wooing some 2 000 expatriate Chinese under the age of 55 who hold a foreign doctoral degree and are full professors at well-known institutions of learning, experienced corporate executives and entrepreneurs with patents for core technologies under their belt. The state has agreed to give each recruit RMB 1 million as a start-up subsidy. In parallel, the host institution or enterprise will provide housing of 150–200 m^2 and a salary to match that earned overseas, or almost; a national title is also bestowed upon the recruit.

In late 2010, a new component was added to the Thousand Talents Programme, targeting aspiring young scientists and engineers aged 40 years and under who hold a doctorate from a well-known foreign university, have at least three years of overseas research experience and hold a formal appointment at a well-known foreign university, research institute or company. The recruit is required to work full-time at a Chinese institution for an initial period of five years. In return, he or she receives a subsidy of RMB 500 000 and a research grant worth RMB 1–3 million.

By 2015, the programme had signed up some 4 100 Chinese expatriates and foreign experts with impeccable credentials. Wang Xiaodong, a prestigious Howard Hughes Medical Institute investigator who was elected

Table 23.2: **China's mega-engineering programmes to 2020**

The 16 mega-engineering programmes correspond to about 167 smaller projects. Thirteen have been made public.

Advanced manufacturing technology	Extra large-scale integrated circuit manufacturing technology and associated technology
	Advanced computerized numerical control machinery and basic manufacturing technology
Transportation	Large aircraft
Agriculture	Cultivation of new varieties of genetically modified organisms (Box 23.3)
Environment	Water pollution control and governance (Box 23.4)
Energy	Large-scale oil and gas fields and coal-bed methane development
	Advanced large-scale pressurized water reactors and nuclear power plants with high-temperature, gas-cooled reactors (Box 23.5)
Health	Development of significant new drugs
	Prevention and treatment of AIDS, viral hepatitis and other major infectious diseases
ICTs	Core electronic devices, high-end generic chips and basic software
	Next-generation broadband wireless mobile communication
Space technologies	High-resolution Earth observation system
	Human space flight and the Moon exploration programme

Source: National Medium- and Long-term Plan for the Development of Science and Technology (2006–2020)

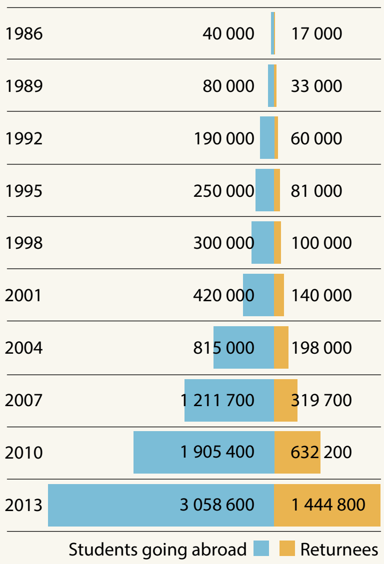
to the US National Academy of Sciences in 2004 at the tender age of 41, and Shi Yigong, a chair professor of structural biology at Princeton University, figure among the prize catches.

The Thousand Talents Programme is not flawless, be it in design or implementation. For one thing, the criteria have changed over time. The programme originally targeted full professors at well-known foreign universities or their equivalents; in practice, the threshold has been lowered to full professors from any institution or even associate professors. Preferential treatment that was originally reserved for new recruits has been extended to qualified earlier returnees with retrospective effect. The evaluation of candidates has paid most attention to academic publications and the required length of full-time employment has been reduced to six months. Given that many, if not most, of the recruits only spend a couple of months in China, even though their contract usually specifies otherwise, the Department of Organization has had to introduce a short-term two-month employment scheme. This not only significantly departs from the programme's original goal but also casts doubt as to whether the programme will encourage the permanent return of outstanding expatriates. This setback suggests that high-flying expatriate Chinese still don't feel the environment is ready for making their move permanent, despite a generous pay package. Among the reasons for this reluctance: personal relationships (*guanxi*) often override considerations of merit in China when it comes to reviewing grant proposals, promotion and awards; rampant misconduct has also tainted the Chinese scientific community; and, in social sciences, some research areas remain taboo.

The Department of Organization has never published the formal list of beneficiaries, for fear that recruits might be frowned upon by their foreign employers or even lose their position through a conflict of interest.

The programme has also alienated domestically trained talent, whose training has been perceived as being of inferior quality, and early returnees, who were treated less generously than more recent recruits. In order to correct these failings, the Department of Organization launched a Ten Thousand Talents Programme, in August 2012 which offers similar perks to a wider range of hopefuls.

Figure 23.7: **Cumulative number of Chinese students going abroad and returnees, 1986–2013**



Source: Author's research

endogenous innovation in a constantly mutating international environment. The mid-term review also included an exercise in which more than 8 000 domestic and foreign experts were invited to assess China's mega-engineering programmes, including through technology foresight studies, to determine where China stood in these technological areas (Table 23.2). Beijing, Jiangsu, Hubei, Sichuan, Liaoning and Qingdao were all selected as sites for the mid-term review at the provincial and municipal levels.

The review was originally due for completion by March 2014 and its preliminary findings were scheduled for distribution to the public by the end of June the same year. However, the second meeting of the steering committee was only held on 11 July 2014. Once the assessment has been completed, the review team will summarize the information collected on the *Medium- and Long-Term Plan's* implementation thus far and the role that science and technology have played since 2006 in driving socio-economic development. Recommendations will then be made for adjusting the implementation plan accordingly. The outcome of the review will also feed into the formulation of the *Thirteenth Five-Year Plan* (2016–2020) and the launch of the S&T systemic reform.

It would nevertheless appear that the review of the *Medium-and Long-Term Plan* will re-affirm the so-called 'whole nation system' (*juguo tizhi*) approach, by which the nation's resources are channelled towards select prioritized areas.[4] This approach is reminiscent of the state-led development of China's strategic weapons programmes (*liangdan yixing*) from the mid-1960s onwards through resource concentration and mobilization. Along with the introduction of 'top-level design' into the formulation of reform initiatives, it may become a hallmark of innovation in China in the years to come.

4. This approach originated from China's state-run sports system, or 'whole nation system' where it was the practice to concentrate the entire nation's resources on the training of athletes who showed promise for winning China medals at the Olympic Games. The success of China's strategic weapons programmes in the 1960s and 1970s and subsequent national defence programmes has been attributed to such a metaphor, which is also used to describe the 16 mega-engineering programmes launched under the *Medium- and Long-Term Plan* to 2020.

Box 23.3: **Cultivating a new variety of GMOs: a mega-engineering programme**

This programme was officially launched on 9 July 2008 when the State Council gave it the go-ahead after debating whether China should commercialize particular genetically modified organisms (GMOs) and, if so, when, as well as how to establish a stringent biosafety and risk assessment mechanism. This is arguably the most controversial of the 16 mega-engineering programmes.

Run by the Ministry of Agriculture, the programme aims to obtain genes with far-reaching applicability and indigenous intellectual property rights and to cultivate major new GMO varieties with traits for disease and insect resistance, stress tolerance and high yields, to promote efficient agricultural production, raise the overall level of agricultural transgenic technology and commercialization and underpin the sustainable development of Chinese agriculture with strong scientific support. Between 2009 and 2013, the central government's appropriation to the programme totalled RMB 5.8 billion.

Current work includes developing GM crops with resistance to virus, diseases, insects, bacteria and fungi, as well as tolerance to weed-killing herbicides. GM crops such as wheat, maize, soybean, potato, canola, peanut and others are at different stages of laboratory studies, field trials or environmental release but have not yet reached the stage of biosafety certification permitting commercialization.

In the past couple of years, China has witnessed a change in policy towards transgenic technology and especially GM crops, which coincided with the change in the political leadership in late 2012 and early 2013. China's position on the issue of transgenic plants was elaborated in Xi Jinping's speech at the central conference on rural work on 23 December 2013. He said that it is quite normal for there to be doubts and debate, as transgenic plants use a novel technology but that it has broad prospects for development. Xi emphasized the importance of strictly following technical regulations and specifications formulated by the state, proceeding steadily to ensure no mishap and taking safety into account. He also indicated that China should boldly carry out research and innovation, take the commanding heights of transgenic technology and not allow foreign companies to occupy China's market for agricultural GM products.

Soon after the programme's inception, the long-delayed biosafety certification process for GM crops was accelerated to allow biosafety certificates to be issued for two strains of GM rice and phytase maize in 2009. These biosafety certificates expired in August 2014, amid rising contestation from anti-GMO activists. The certificates were nevertheless renewed on 11 December 2014. It remains to be seen whether the GMO mega-engineering programme will proceed smoothly over the next five years.

Source: www.agrogene.cn; author's research

Reform of the Chinese Academy of Sciences

The latest reform of CAS once again raises the question of the academy's place in China's national S&T system, a question which first came up at the academy's inception immediately after the founding of the People's Republic of China in 1949. At the time, research and training were separated at universities and industrial R&D institutes focused on specific problems in their particular sectors. These were the glory days of the academy, when it contributed, in particular, to the success of the strategic weapons programmes through a mission-oriented disciplinary development strategy.

CAS would quickly become a victim of its own success, after its high visibility attracted keen attention from the political leadership and other actors in the S&T system. In the mid-1980s when China began reforming its S&T system, CAS was forced to adopt a 'one academy, two systems' approach. This strategy consisted in concentrating a small number of scientists on basic research and following the global trend in high technology, while encouraging the majority of its staff to engage in the commercialization of research results and projects of direct relevance to the economy. The overall quality of research suffered, as did the academy's ability to tackle fundamental research questions.

In 1998, the president of CAS, Lu Yongxiang, initiated the Knowledge Innovation Programme to improve the academy's vitality (Suttmeier *et al.*, 2006a; 2006b). Initially, CAS hoped to satisfy the Chinese leadership by making the staff of its institutes more nimble and mobile. The academy's very existence was threatened, however, after it was downsized to compensate for the government's efforts to strengthen the research capability of universities and the national defence sector – ironically, the very sector that had historically absorbed CAS personnel or depended upon CAS to take on major research projects. In reaction, CAS not only reversed its early approach but even went to the other extreme by significantly expanding its reach. It established application-focused research institutes in new scientific disciplines and new cities and formed alliances with provincial and local governments and industries. The Suzhou Institute of Nanotech and Nanobionics is one such establishment; it was created jointly by CAS and the Jiangsu provincial and Suzhou municipal governments in 2008. Apparently, some of these new institutes are not fully supported by the public purse; in order to survive, they have to compete with existing institutes and engage in activities that bear little relation to CAS's mission as the national academy. Although CAS hosts the world's largest graduate school in terms of the number of postgraduate degrees awarded each year, which include 5 000 PhDs, CAS has been finding it difficult in recent years to attract the best and brightest students. This has spurred CAS to found two affiliated universities in Beijing and Shanghai, both of which opened their doors to a couple of hundred undergraduates in 2014.

CAS: full of promise but overstretched

Today, CAS employs a staff of 60 000 and counts 104 research institutes. It operates on a budget of roughly RMB 42 billion (*circa* US$ 6.8 billion), just under half of which comes from the government. The academy is struggling with a number of challenges. For one thing, it is in direct competition with other Chinese institutions of learning for funding and talent. Underpaid CAS scientists also have to apply constantly for grants to supplement their income, a widespread phenomenon in the entire research and higher education sector, which may have resulted in underperformance. CAS has also seen its work duplicated on a large scale by its own institutes, which tend not to collaborate with each other. There is also a lack of interest among CAS scientists in seeking opportunities to apply their research to the economy, although this should not be its core mission. Last but not least, the academy is encumbered by the breadth of its mandate, which ranges from research, talent training, strategic high-tech development, commercialization of research results and local engagement to the provision of policy advice as a think tank and through its elite academicians; this makes it extremely difficult for CAS to manage and evaluate institutes and individual scientists. In a word, the academy is big and full of promise, yet so cumbersome, weighed down by the legacy of the past (Cyranoski, 2014a).

Reform or be reformed!

In the past couple of years, CAS has come under enormous pressure from the political leadership to produce visible achievements. The loss of independence of the Russian Academy of Sciences, the successor to the Soviet Academy of Sciences on which CAS was modelled, in a top-down reform in 2013 (see Box 13.2), has sent a chilling signal: if CAS does not reform itself, others will. This realization prompted current CAS President Bai Chunli to take advantage of Xi's call for CAS to become 'a pioneer in four areas' (see p. 628) to propose a sweeping reform of the academy through a new Pioneering Action Initiative (*shuaixian xingdong jihua*). The aim of this initiative is to orient the academy towards the international frontier of science, major national demands and the battleground for the national economy by re-organizing existing institutes into four categories:

- centres of excellence (*zhuoyue chuangxin zhongxin*) focused on basic science, especially in those areas where China has a strong advantage;
- innovation academies (*chuangxin yanjiuyuan*) targeting areas with underdeveloped commercial potential;
- centres of big science (*dakexue yanjiu zhongxin*) built around large-scale facilities to promote domestic and international collaboration; and
- institutes with special characteristics (*tese yanjiusuo*) devoted to initiatives that foster local development and sustainability (Cyranoski, 2014a).

Box 23.4: **Water body pollution control and treatment: a mega-engineering programme**

The mega-engineering programme of water body pollution control and treatment has been designed to address the technology bottleneck in China's efforts to control and treat pollution of water bodies. In particular, the programme aims to achieve a breakthrough in key and generic technologies related to water pollution control and treatment, such as industrial pollution source control and treatment, agricultural non-point source pollution control and treatment, urban sewage treatment and recycling, purification and the ecological restoration of water bodies, drinking water safety and water pollution monitoring and early warning.

The programme focuses on four rivers (Huai, Hai, Liao and Songhua), three lakes (Tai, Chao and Dianchi) and the Three Gorges Reservoir, the largest dam in the world. Projects have been carried out within the six major themes of monitoring and early warning, city water environment, lakes, rivers, drinking water and policies.

The Ministry of Environmental Protection and the Ministry of Housing and Urban and Rural Construction are in charge of the programme, which got under way on 9 February 2009 with a budget of more than RMB 30 billion. The first stage of the programme to early 2014 targeted breakthroughs in key technologies to control source pollution and reduce wastewater discharge. The second stage is currently targeting breakthroughs in key technologies to fix the water bodies. The main goal of the third stage will be to make technological breakthroughs in comprehensive control of the water environment.

The first stage focused on the entire process wastewater treatment technology for heavily polluting industries, comprehensive treatments for heavily polluted rivers and lakes suffering from eutrophication, non-point source pollution control technology, water quality purification technologies, water-related environmental risk assessment and early warning, as well as key remote monitoring technology. Comprehensive demonstration projects were carried out in the Tai Lake basin to improve water quality and eliminate water from rivers running through cities that is of Class-V quality, which means it is only suitable for irrigation and landscaping. The first-stage projects also targeted problems related to drinking water. There have also been some achievements in water resources protection, water purification, safe distribution, monitoring, early warning, emergency treatment and safety management.

Source: http://nwpcp.mep.gov.cn

The reclassification of the CAS institutes and their scientists was still under way in 2015. It must be said that the initiative itself is self-congratulatory, as the academy is still resting on its past achievements, with little consideration for whether this new initiative may be good for the nation as well as for the academy. This explains why some are sceptical about the necessity of maintaining such a gigantic organization, a model not found anywhere else in the world.

The initiative offers the academy a bright future, as long as it can count on sizable government funding – but that is nothing new. Many of the goals that President Bai Chunli proposed for the Pioneering Action Initiative are identical to those of his predecessor, Lu Yongxiang, through his own Knowledge Innovation Programme. Nor is there any guarantee that these goals will be fulfilled through the reform.

The Pioneering Action Initiative is pivoting institutions into a new matrix so as to boost collaboration within the academy and concentrate on tackling key research questions, which has a certain logic. Implementation will be tough, though, since many institutes do not fit easily into any of the four defined categories. Another worry is that the initiative may not necessarily encourage collaboration with scientists external to CAS. The danger is that CAS may actually become even more hermetic and isolated than before.

The timing of the reform may also complicate matters. The reform at CAS coincides with the nationwide reform of public institutions (*shiye danwei*) launched in 2011. In general, the country's 1.26 million public institutions of education, research, culture and health care, which have more than 40 million employees, fall into two types. CAS institutes that fall into Type 1 are to be fully financed from the public purse and will be expected to fulfil only the tasks set by the state. Type II CAS institutes, on the other hand, will be allowed to supplement partial public funding with income earned through other activities, including through government procurement of their research projects, technology transfer and entrepreneurship. The reform will thus have implications both for the institutes and for individual scientists, in terms of the amount of stable funding they receive and the level of salaries, as well as the scope and importance of the executed projects. It is also likely that some CAS institutes will be corporatized, as this is what has happened to China's application-oriented R&D institutes since 1999. Consequently, CAS will need to become a leaner institution, as the state may not always be willing or able to finance such a costly academy.

Box 23.5: **Large-scale advanced nuclear power stations: a mega-engineering programme**

In 2015, China had 23 operable nuclear reactors and a further 26 were under construction. The country's large-scale nuclear power station programme has three components: advanced pressurized water reactors (PWR), special high-temperature reactors (HTR) and used fuel reprocessing. The central government is expected to invest RMB 11.9 billion and RMB 3 billion respectively in the two nuclear reactor sub-programmes.

The PWR sub-programme is being implemented by the State Nuclear Power Technology Corporation (SNPTC). It aims to digest and absorb imported third-generation nuclear power technology, which will then serve as the basis for developing more powerful large-scale advanced PWR technology, and to generate indigenous intellectual property rights.

The programme has three stages. Initially, the Westinghouse Electric Company, now a unit of Japanese engineering and electronics giant Toshiba, is helping SNPTC to build four advanced, passive units with an installed capacity of about 1 000 MW each (AP 1 000 units), through which SNPTC masters the basic design capability for third-generation nuclear power technology. At the second stage, SNPTC will develop a standardized design capability of AP 1 000 units, as well as the ability to build AP 1 000 units in both coastal and inland areas, with support from Westinghouse. By the third stage, SNPTC should be capable of designing advanced, passive third-generation nuclear reactors units of 1400 MW (Chinese AP 1 400); it should also be ready to build a CAP 1 400 demonstration unit and undertake a pre-research programme for the larger CAP 1 700 units.

The programme was launched on 15 February 2008. The construction of the AP 1 000 units in Sanmen in Zhejiang province and Haiyang in Shandong province got under way in 2009. Construction was put on hold, however, after the earthquake-induced nuclear disaster in Japan in March 2011 (see Chapter 24). Construction resumed in October 2012 and four AP 1 000 units are now expected to be online by late 2016.

SNPTC has been co-ordinating domestic nuclear power equipment manufacturers, research institutes and universities, which are in the process of assimilating imported equipment design and manufacturing technology and localizing key equipment used in the AP 1 000. Some key equipment has already been shipped to the Sanmen and Haiyang sites. In 2014, the first reactor pressure vessel for the second AP 1 000 unit in Sanmen was manufactured domestically.

In December 2009, SNPTC and the China Huaneng Group formed a joint venture to start a CAP 1 400 demonstration project in Shidaowan in Shandong province. The conceptual design passed the state's evaluation test at the end of 2010 and a preliminary design was completed in 2011. In January 2014, the National Energy Administration organized the expert review of the project and, in September, the National Nuclear Safety Administration approved the design safety analysis following a 17-month review. Key equipment for CAP 1 400 is currently being manufactured and the related demonstration project, which is due to start soon, is expected to localize 80% of the nuclear island equipment. Safety tests for key components used in CAP 1 400 unit have also gone ahead. The demonstration and standardized units of the CAP 1 400 demonstration project should be operational by 2018 and 2019 respectively.

Meanwhile, also in Shidaowan, a HTR-20 demonstration project is already up and running. The project will develop the world's first fourth-generation demonstration reactor, on the basis of the 100 MW HTR-10 prototype pebble-bed reactor developed by Tsinghua University.

Tsinghua University began building the HTR-10 reactor back in 1995. This fourth-generation nuclear energy technology is modelled on the German HTR-MODUL. The reactor was fully operational by January 2003. HTR-10 is claimed to be fundamentally safer, potentially cheaper and more efficient than other nuclear reactor designs. Operated at high temperatures, it generates hydrogen as a by-product, thus supplying an inexpensive and non-polluting fuel for fuel cell-powered vehicles.

Huaneng, the China Nuclear Energy Construction Company and Tsinghua University have established a joint venture to scale up the HTR experimental design and engineering technology, as well as high-performance fuel cell batch preparation techniques. Postponed after the Fukushima nuclear disaster in March 2011, the project finally got under way in late 2012. When it comes online in 2017, the Shidaowan project will have its first two 250 MW units, which together will drive a steam turbine generating 200 MW.

The third component of this mega-engineering programme concerns the construction of a large commercial spent fuel reprocessing demonstration project to achieve a closed fuel cycle.

Source: www.nmp.gov.cn

Rethinking government funding of research

Another major reform is this time shaking up the way in which the Chinese government funds research. China has seen rising central government expenditure on science and technology over the past decade. With RMB 236 billion (US$ 38.3 billion) in 2013, spending on science and technology accounted for 11.6% of the central government's direct public expenditure. Of this, R&D expenditure has been estimated at about RMB 167 billion (US$ 27 billion) by the National Bureau of Statistics (2014). As new national science and technology programmes had been added over the years, especially the mega-engineering programmes introduced under the *Medium- and Long-Term Plan* after 2006, funding had become decentralized and fragmented, resulting in widespread overlap and an inefficient use of funds. For example, about 30 different agencies administered the central government R&D funding through some 100 competitive programmes up until the launch of the new reform. To compound matters, pervasive corruption and misaligned incentives were seen as weakening the vitality of China's research enterprise (Cyranoski, 2014b**)**. Change seemed inevitable.

Once again, the reform was instigated under the pressure of the political leadership. Initially, the measures proposed by the Ministry of Science and Technology (MoST) and the Ministry of Finance only made small adjustments to the existing system. All the major programmes were to be maintained and linked to one another, with the integration of small programmes, and new procedures for supporting research were to be introduced, along with other measures to avoid repetition and strengthen co-ordination between ministries. The Central Leading Group for Financial and Economic Affairs turned down several drafts of the reform proposal. It was only after the Central Leading Group for Financial and Economic Affairs contributed substantial input of its own that the measure was finally approved by the Central Leading Group for the Deepening of Comprehensive Reform, the Politburo of the CCP's Central Committee and the State Council. The reform re-organizes the nation's R&D programmes into five categories:

- Basic research through the National Natural Science Foundation of China, which currently distributes many of the small-scale competitive grants;
- Major national science and technology programmes, which are presumably the mega-science and mega-engineering programmes under the *Medium- and Long-Term Plan* to 2020;
- Key national research and development programmes, which presumably succeed the State High-Technology R&D Programme, also known as the 863 Programme, and the State Basic Research and Development Programme, also known as the 973 Programme;[5]
- A special fund to guide technological innovation; and
- Special programmes to develop human resources and infrastructure (Cyranoski, 2014b).

These five categories translate into some RMB 100 billion (US$ 16.36 billion), or 60% of the central government's funding for research in 2013, which will be handled by professional organizations specializing in research management by 2017. MoST, which distributed RMB 22 billion (US$ 3.6 billion) in public R&D funding in 2013, will gradually concede its role of administering the funding for programmes under its jurisdiction, most noticeably the 863 and 973 Programmes (Figure 23.8). Some other ministries with a portfolio for science and technology will likewise relinquish their power to distribute public research funds. In return, MoST will survive the reform intact, rather than being dissolved as had been debated for quite some time. The ministry will henceforth be in charge of formulating policy and monitoring the use of funding. In line with the reform, the ministry is restructuring to reorganize relevant departments. For example, its Planning and Development Bureau and Scientific Research Conditions and Finance Bureau have been merged to form the new Resource Allocation and Management Bureau to strengthen operational oversight of the future interministerial conference mechanism. Officials at bureau chief level have also been reshuffled within the ministry.

The interministerial conference mechanism is led by MoST with the participation of the Ministry of Finance, National Development and Reform Commission (NDRC) and others. The interministerial conference is responsible for planning and reviewing strategies for S&T development, determining national S&T programmes and their key tasks and guidelines and overseeing the professional research management organizations that will be formed to review and approve funding for national science and technology programmes. The interministerial conference will be supported by a committee responsible for strategic consulting and comprehensive review, which will be convened by MoST and composed of leading experts from the scientific community, industry and various economic sectors.

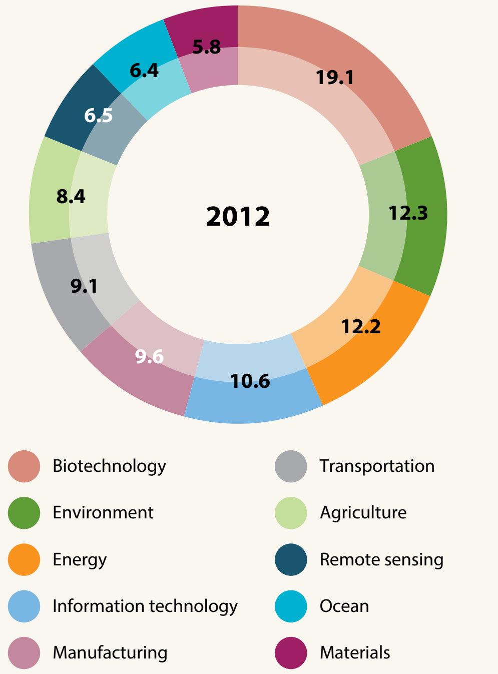
At the operational level, professional research management organizations will be established. Through a 'unified platform' or a national S&T information management system, they will organize project submission, evaluation, management and assessment. MoST and the Ministry of Finance will be responsible for reviewing and supervising the performance evaluation of the funding for national science and technology programmes, evaluating the performance of members of the strategic consulting and comprehensive review committee and the performance of the professional research management organizations. The procedures of programmes and projects will be adjusted as part of the dynamic evaluation and

5. For details of these programmes, see the *UNESCO Science Report 2010*.

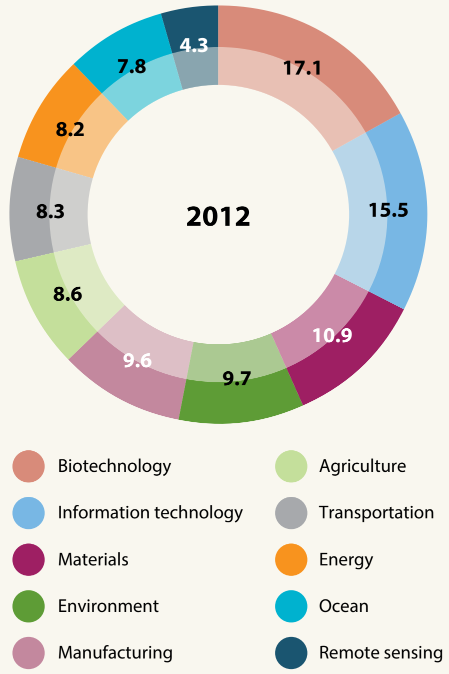
Figure 23.8: **Priorities of China's national research programmes, 2012**

PRIORITIES OF CHINA'S NATIONAL PROGRAMME FOR HIGH-TECH R&D (863 PROGRAMME)

Distribution of new projects by field (%)

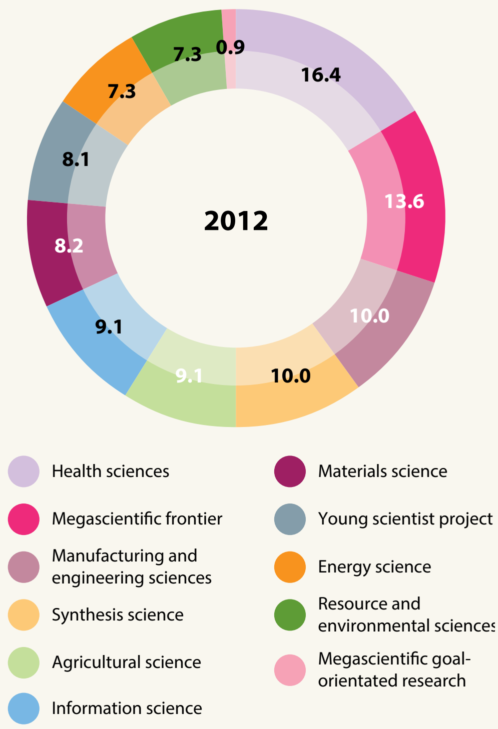


Distribution of budget for new projects by field (%)

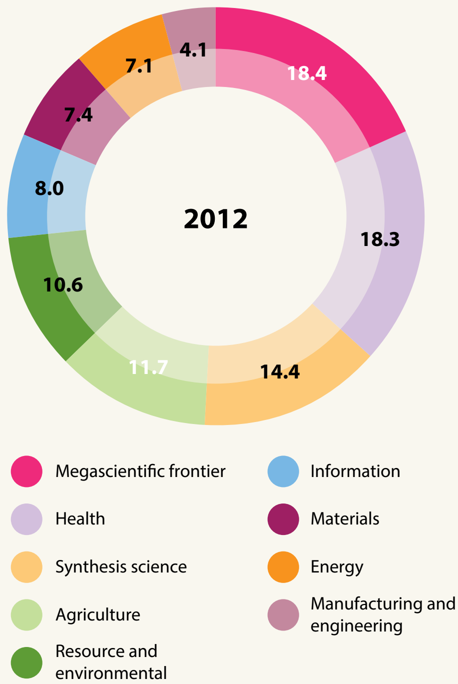


PRIORITIES OF CHINA'S NATIONAL PROGRAMME FOR KEY BASIC R&D (973 PROGRAMME)

Distribution of new projects by field (%)



Distribution of budget by field (%)



Source: Planning Bureau of Ministry of Science and Technology (2013) *Annual Report of the National Programmes of Science and Technology Development.*

monitoring process. The 'unified platform' will also collect and report information on national S&T programmes, including budget, personnel, progress, outcomes and evaluation and assessment, thus subjecting the entire process of research management to public scrutiny.

As yet, it is unclear how the professional research management organizations will be established and, above all, how they will operate. One possibility would be to transform the existing research management organizations, including those under MoST and other government ministries handling similar tasks. The question then becomes how to avoid 'putting new wine into an old bottle,' as opposed to changing fundamentally the way in which the government funds national science and technology programmes. The idea of professional research management organizations has been inspired by the UK model; in the UK, public funds destined for research are distributed through seven research councils for the arts and humanities, biotechnology and biological sciences, engineering and physical sciences, economic and social sciences, medical sciences, the natural environment and science and technology. This begs the question of how to integrate the existing programmes under different ministries according to the logic of scientific research rather than arbitrarily assigning them to the various professional research management organizations. Meanwhile, some government ministries may be reluctant to relinquish their control over funding.

An environmental action plan

China, along with India and other emerging economies, has long insisted on the principle of 'common but differentiated responsibilities' in dealing with global climate change. However, as the world's largest greenhouse gas (GHG) emitter, China is most susceptible to the adverse effects of climate change, mainly in agriculture, forestry, natural ecosystems, water resources (Box 23.4) and coastal areas. Irreversible climate change could throttle China's rise as a great power and environmental damage, GHG emissions and rising temperatures could derail China's path to modernity. Indeed, China has been facing the challenge of balancing its multiple development goals, which range from industrialization, urbanization, employment and exports to sustainability and include the target of doubling GDP by 2020. By reducing its GHG emissions and cleaning up the environment, the political leadership is also likely to gain further support from the emerging middle class; this support will be necessary to maintain the legitimacy of the Chinese Communist Party and help overcome other domestic challenges.

These concerns have prompted the Chinese government to come up with policies for energy conservation and GHG emissions reduction. In 2007, NDRC released the National Climate Change Programme, which proposed reducing unit GDP energy consumption by 20% by 2010 from 2005 levels, in order to reduce China's carbon dioxide (CO_2) emissions. Two years later, the government went a step further, establishing a target of reducing unit GDP CO_2 emissions by 40–45% by 2020 from 2005 levels. The reduction in energy consumption became a binding target in the *Eleventh Five-Year Plan* (2006–2010). The *Twelfth Five-Year Plan* (2011–2015) set the targets of reducing unit GDP energy consumption by 16% and CO_2 emissions by 17% by 2015. However, China did not meet the energy target in the *Eleventh Five-Year Plan* (2005–2010) and the *Twelfth Five-Year Plan* was also behind schedule in the first three years for reaching its targets, despite the enormous pressure brought to bear on local officials by the central leadership.

On 19 September 2014, China's State Council unveiled an *Energy Development Strategy Action Plan (2014–2020)* which promised more efficient, self-sufficient, green and innovative energy production and consumption. With the cap of annual primary energy consumption set at 4.8 billion tons of standard coal equivalent until 2020, the plan's long list of targets for building a modern energy structure includes:

- reducing unit GDP CO_2 emissions by 40–50% over 2005 levels;
- increasing the share of non-fossil fuels in the primary energy mix from 9.8% (2013) to 15%;
- capping total annual coal consumption at roughly 4.2 billion tons;
- lowering the share of coal in the national energy mix from the current 66% to less than 62%;
- raising the share of natural gas to above 10%;
- producing 30 billion m^3 of both shale gas and coalbed methane;
- having an installed nuclear power capacity of 58 Gigawatts (GW) and installations with a capacity of more than 30 GW under construction;
- increasing the capacity of hydropower, wind and solar power to 350 GW, 200 GW and 100 GW respectively; and
- boosting energy self-sufficiency to around 85%.

As China burned 3.6 billion tons of coal in 2013, capping total coal consumption at roughly 4.2 billion tons means that China can only increase its coal usage by roughly 17% by 2020 from 2013 levels. The cap also means that annual coal consumption may only grow by 3.5% or less between 2013 and 2020. To compensate for the drop in coal consumption, China plans to expand its nuclear energy production with the construction of new nuclear power stations (Box 23.5) and the development of hydropower, wind and solar energy (Tiezzi, 2014).

There are several reasons for China's emphasis on diversifying its energy mix. In addition to environmental considerations, China is eager to reduce its reliance on foreign energy suppliers. Currently, China receives nearly 60% of its oil and over 30% of its natural gas from foreign sources. For domestic production to make up 85% of total energy consumption by 2020, China will need to increase its production of natural gas, shale gas and coalbed methane. The new energy action plan also calls for deepwater drilling, as well as for the development of oil and gas extraction in its neighbouring seas by undertaking both independent extraction projects and co-operative projects with foreign countries (Tiezzi, 2014).

A week before the announcement of the new energy action plan, President Xi Jinping signed a joint climate change agreement with US President Barack Obama, in which China undertook to raise the share of non-fossil fuel sources to 20% of its energy mix by 2030. China also agreed to slow down then stop the increase in its GHG emissions by 2030; in turn, the USA pledged to reduce its own GHG emissions by up to 28% by 2025 relative to 2005 levels. Both presidents also agreed to co-operate in the fields of clean energy and environmental protection. Whereas China and the USA had blamed one another for the failure of the 2009 summit on climate change in Copenhagen to reach an agreement on setting emissions reduction targets, now there is strong hope that the negotiations might culminate in an agreement at the climate change conference in Paris in late 2015.

Amid all these positive developments, the Standing Committee of the National People's Congress – China's legislature – passed the *Amendment to Environmental Protection Law* on 24 April 2014, marking the end of a three-year revision of China's environmental protection law. The new law, which took effect on 1 January 2015, stipulates harmonizing socio-economic development with environmental protection and, for the first time, establishes clear requirements for building an ecological civilization. Perceived to be the most stringent in China's environmental protection history, the law toughens the penalties for environmental offences with specific articles and provisions for tackling pollution, raising public awareness and protecting whistle-blowers. It also places greater responsibility and accountability on local governments and law enforcement bodies for environmental protection, sets higher environmental protection standards for enterprises and imposes harsher penalties for such acts as tampering with and falsifying data, discharging pollutants deceptively, not operating pollution prevention and control facilities normally and evading supervision, among others (Zhang and Cao, 2015).

CONCLUSION

Realizing the 'China Dream' will not be unconditional

China's new political leadership has placed STI at the core of the reform of its economic system, as innovation can help not only with restructuring and transforming the economy but also with solving other challenges that China faces – from inclusive, harmonious and green development to an ageing society and the 'middle income trap.' The period from now to 2020 seems to be critical for the comprehensive deepening of reform, including the reform of the S&T system. As we have seen, new initiatives have been launched to reform the Chinese Academy of Sciences and the centrally financed national S&T programmes, in order to increase China's chances of becoming an innovation-oriented, modern nation by 2020.

The reform is necessary but it is still too early to predict whether it will lead China in the right direction and, if so, how quickly it will contribute to China's ambition of becoming an innovation-oriented nation. Particular concerns are the extent to which the reform reflects a 'top-level design', at the expense of the consultations with stakeholders and the public, coupled with the integration of bottom-up initiatives that proved crucial for the formulation and implementation of S&T policy in the earlier reform and open-door era. The merit of the 'whole nation system' also needs to be carefully assessed against the trend of globalization, which not only served as the backdrop to China's rise in economic and technological terms during the reform and open-door era but also brought China enormous benefits.

As we have seen, the level of dependence of Chinese enterprises on foreign core technologies is of some concern. The current political leadership has reacted by setting up an expert group under Vice-Premier Ma Kai to identify industrial 'champions' capable of concluding strategic partnerships with foreign multinationals. This resulted in Intel acquiring 20% of the shares in Tsinghua Unigroup, a state company emanating from one of the country's most prestigious universities, in September 2014. At the time of writing in July 2015, the *Wall Street Journal* had just revealed an offer by Tsinghua Unigroup to purchase Micron, a US manufacturer of semiconductors, for € 20.8 billion. Should the deal go ahead, it will be the biggest foreign takeover concluded by a Chinese firm since the China National Offshore Oil Corporation purchased the Canadian oil and gas company Nexen Inc. in 2012 for US$ 15 billion.

Knowledge transfer is evidently embedded in China's foreign direct investment and the efforts of the returnees, who are now active at the forefront of technology and innovation in China. Although the political leadership still calls for globalization to be embraced, recent cases of bribery and anti-monopoly moves targeting multinational companies operating in China, coupled with the restrictions on access to information and the current anti-Western values rhetoric, may lead to an exodus of capital and talent.

The smooth running of China's S&T system and, indeed, the economy as a whole, can be impacted by unstable domestic developments and unexpected external shocks. During the 30-plus-year reform and open-door era from 1978 onwards, scientists and engineers enjoyed a largely stable and favourable working environment which fostered professional satisfaction and career advancement. Chinese science and technology progressed at an impressive pace in an environment that was less politicized, interventionist and disruptive than today. China's scientific community is conscious that its work environment will need to be conducive to creativity and the cross-pollenization of ideas, if it is to contribute effectively to achieving the 'China Dream' envisaged by the country's political leadership.

KEY TARGETS FOR CHINA

- Raise GERD to 2.50% of GDP by 2020;
- Raise the contribution of technological advances to economic growth to more than 60% by 2020;
- Limit China's dependence on imported technology to no more than 30% by 2020;
- Become, by 2020, one of the top five countries in the world for the number of invention patents granted to its own citizens and ensure that Chinese-authored scientific papers figure among the world's most cited;
- Reduce (unit GDP) CO_2 emissions by 40–50% by 2020 from 2005 levels;
- Increase the share of non-fossil fuels in the primary energy mix from 9.8% (2013) to 15% by 2020;
- Cap annual coal consumption at roughly 4.2 billion tons by 2020, compared to 3.6 billion tons in 2013, and lower the share of coal in the national energy mix from 66% at present to less than 62% by 2020;
- Raise the share of natural gas to above 10% by 2020;
- Produce 30 billion m^3 of both shale gas and coalbed methane by 2020;
- Achieve an installed nuclear power capacity of 58 Gigawatts (GW) and installations with a capacity of more than 30 GW under construction by 2020;
- Increase the capacity of hydropower, wind and solar power to 350 GW, 200 GW and 100 GW respectively by 2020;
- Boost energy self-sufficiency to around 85%.

REFERENCES

Cao, C.; Li, N.; Li, X. and L. Liu (2013) Reforming China's S&T system. *Science,* 341: 460–62.

Cao, C.; Suttmeier, R. P. and D. F. Simon (2006) China's 15-year science and technology Plan. *Physics Today,* 59 (12) (2006): 38–43.

Cyranoski, D. (2014a) Chinese science gets mass transformation. *Nature,* 513**:** 468–9.

Cyranoski, D. (2014b) Fundamental overhaul of China's competitive funding. *Nature* (24 October). See: http://blogs.nature.com.

Ghafele, R. and B. Gibert (2012) *Promoting Intellectual Property Monetization in Developing Countries: a Review of Issues and Strategies to Support Knowledge-Driven Growth*. Policy Research Working Series 6143. Economic Policy and Debt Department, Poverty Reduction and Economic Management Network, World Bank.

Gough, N. (2015) Default signals growing maturity of China's corporate bond market. *New York Times*, 7 March.

Liu, F.-C.; Simon, D. F.; Sun, Y.-T. and C. Cao (2011) China's innovation policies: evolution, institutional structure and trajectory. *Research Policy,* 40 (7): 917–31.

Lozano, R. *et al.* (2012) Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the global burden of disease study 2010. *The Lancet,* 380: 2095–128.

National Bureau of Statistics (2014) *China Statistical Yearbook 2014*. China Statistical Press. Main Items of Public Expenditure of Central and Local Governments.

OECD (2014) *Science, Technology and Industry Outlook 2014*. November. Organisation for Economic Co-operation and Development: Paris.

Simon, D. F. (2010) China's new S&T reforms and their implications for innovative performance. Testimony before the US–China Economic and Security Review Commission, 10 May 2010: Washington, DC. See www.uscc.gov/sites/default/files/5.10.12Simon.pdf.

Suttmeier, R.P. (2007) Engineers rule, OK? *New Scientist*, 10 November, pp. 71–73.

Suttmeier, R.P.; Cao, C. and D. F. Simon (2006a) 'Knowledge innovation' and the Chinese Academy of Sciences. *Science,* 312 (7 April):58–59.

Suttmeier, R.P.; Cao, C. and D. F. Simon (2006b) China's innovation challenge and the remaking of the Chinese Academy of Sciences. *Innovations: Technology, Governance, Globalization,* 1 (3):78–97.

Tiezzi, S. (2014) In new plan, China Eyes 2020 energy cap. *The Diplomat*. See: http://thediplomat.com.

UNESCO (2012) All for one and one for all: genetic solidarity in the making. *A World of Science*, 10 (4). October.

Van Noorden, R. (2014) China tops Europe in R&D intensity? *Nature* 505 (14 January):144–45.

Yoon, J. (2007) The technocratic trend and its implication in China. Paper presented as a graduate conference on Science and Technology in Society, 31 March–1 April, Washington D.C.

Zhang, B. and C. Cao (2015) Four gaps in China's new environmental law. *Nature,* 517:433–34.

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Japan needs to adopt forward-looking policies ... and to pursue the necessary reforms to adapt to the changing global landscape.

Yasushi Sato and **Tateo Arimoto**

ASIMO is the culmination of two decades of humanoid robotics research by Honda engineers. ASIMO can run, walk on uneven slopes and surfaces, turn smoothly, climb stairs and reach for and grasp objects. ASIMO can also comprehend and respond to simple voice commands. ASIMO has the ability to recognize the face of a select group of individuals. Using its camera eyes, ASIMO can map its environment and register stationary objects. ASIMO can also avoid moving obstacles as it moves through its environment.
Photo: © http://asimo.honda.com

24 · Japan

Yasushi Sato and Tateo Arimoto

INTRODUCTION

Two turning points in Japanese politics

Twice, Japan has experienced a political turning point in the past decade. The first came in August 2009, with the electoral defeat of the Liberal Democratic Party (LDP), which had dominated Japanese politics for over half a century. Frustrated by the LDP's failure to shake Japan out of a two decade-long economic slump, Japanese voters placed their hopes in the Democratic Party of Japan (DPJ). Three prime ministers followed in quick succession, none of whom succeeded in rebooting the economy. Twenty-one months after the Great East Japan Earthquake triggered a tsunami and the Fukushima nuclear disaster in March 2011, disillusioned voters returned the LDP to power in the December 2012 general election.

The new prime minister, Shinzo Abe, put in place a set of extraordinarily active fiscal and economic policies which have been dubbed Abenomics. After news emerged that Japan had officially slipped into recession following an increase in taxation on consumption, the prime minister called a snap election in December 2014 to consult the public on whether or not to pursue Abenomics. His party won a landslide victory.

Long-term challenges: an ageing society and economic stagnation

Although Abenomics has helped Japan to recover from recession in the wake of the global financial crisis of 2008, the nation's underlying problems remain. Japan's population peaked in 2008 before embarking on a gradual decline. As the proportion of seniors in the nation's population has surged, Japan has become the world's most aged society, even if the fertility rate did rise somewhat between 2005 and 2013, from 1.26 to 1.43 children per woman. The combination of a sluggish economy and ageing society has necessitated the mobilization of increasingly massive government expenditure, especially for social security. The share of accumulated total government debt in GDP exceeded 200% in 2011 and has since continued to climb (Table 24.1). To help service this debt, the Japanese government raised the tax on consumption from 5% to 8% in April 2014. The Abe cabinet then decided to postpone raising this tax further to 10% until April 2017, citing Japan's weak economic performance.

The current fiscal situation is clearly unsustainable. Whereas government expenditure on social security rose steadily from 2008 to 2013 at an average annual rate of 6.0%, total national revenue barely progressed. In May 2014, the International Monetary Fund (IMF) recommended that Japan raise its consumption tax rate to at least 15%. This figure is still much lower than in most European nations but it would be very difficult to implement the IMF's recommendation in Japan, as most people, especially seniors, would overwhelmingly vote against any party responsible for such a decision. At the same time, the Japanese would also resist any drop in the current level of public service, which is characterized by cost-efficient, hospitable and universal health care, fair and reliable public education and trusted police and judicial systems. Politicians have thus been able to do little to contrary the rapidly widening gap between revenue and expenditure.

Under such extraordinary fiscal pressure, the government has indeed tried hard to streamline public expenditure. The defence budget remained roughly constant from 2008 to 2013, although it was then moderately augmented as attention focused on changing geopolitical circumstances in Asia. Spending on public works was radically cut back by the DPJ administration but increased again after the Great East Japan Earthquake, especially under the Abe administration. The budget for education shrank constantly from 2008 to 2013, with the notable exception of DPJ's flagship policy of making secondary school education free of charge, introduced in 2010. After expanding constantly for years, the budget for the promotion of science and technology (S&T) went into reverse. Although the government still sees S&T as a key driver of innovation and economic growth, the combination of limited revenue and rising expenditure for social security does not bode well for public support of S&T in Japan.

In the private sector, too, investment in research and development (R&D) has dropped since the global financial

Table 24.1: **Socio-economic indicators for Japan, 2008 and 2013**

Year	GDP growth, volume (%)	Population (millions)	Share of population aged 65 years and above (%)	Government debt as a share of GDP (%)*
2008	-1.0	127.3	21.6	171.1
2013	1.5	127.1	25.1	224.2

*General government gross financial liabilities

Source: OECD (2014) *Economic Outlook No.96;* IMF World Economic Outlook database, October 2014; for population data: UN Department of Economic and Social Affairs crisis of 2008, along with capital investment. Instead of investing their resources, firms have been accumulating profits to constitute an internal reserve which now amounts to roughly 70% of Japan's GDP. This is because they increasingly feel the need to be prepared for momentous socio-economic changes, even though these are hardly predictable. A 4.5% reduction in the corporate tax rate in 2012, in response to similar global trends, helped Japanese firms amass their internal reserve, albeit at the expense of raising their employees' salaries. In fact, Japanese firms have consistently cut operational costs over the past 20 years by replacing permanent employees with contractors, in order to compete in the global market. After peaking in 1997, the average salary in the private sector had dropped by 8% by 2008 and by 11.5% by 2013, enlarging income disparities. Moreover, as in many advanced nations, young people increasingly find themselves occupying temporary jobs or working as contractors. This makes it difficult for them to acquire skills and gives them little say in their career paths.

'Japan is back!'

It was in the midst of such fiscal and economic distress that Prime Minister Abe came to office in December 2012. He vowed to make Japan's economic recovery his top priority by overcoming deflation, which had afflicted the Japanese economy for nearly two decades. Soon after his inauguration, he made a speech in February 2013 entitled *Japan is Back,* during a visit to the USA. Abenomics consists of 'three arrows,' namely monetary easing, fiscal stimulus and a growth strategy. Investors the world over were intrigued and began paying special attention to Japan in 2013, resulting in a rise of stock prices by 57% in a year. At the same time, overappeciation of the yen, a phenomenon which had tormented Japanese manufacturers, came to an end. The prime minister even urged the private sector to raise employees' salaries, which it did.

The full effects of Abenomics on the Japanese economy are yet to be seen, however. Although the depreciation of the yen has helped Japan's export industry, the extent to which Japanese firms will bring their factories and R&D centres abroad back to Japan remains unclear. A weaker yen has also raised the price of imported goods and materials, including oil and other natural resources, worsening Japan's trade balance.

It appears that, in the end, Japan's long-term economic health will depend on the third arrow of Abenomics, namely, its growth strategy, the key elements of which include enhancing the social and economic participation of women, fostering medical and other growing industries and promoting science, technology and innovation (STI). Whether these goals are achieved will fundamentally affect the future of Japanese society.

TRENDS IN STI GOVERNANCE

A radical departure from the past

It was the Basic Law on Science and Technology (1995) which first mandated the Japanese government to formulate the *Basic Plan for Science and Technology,* the most fundamental document in this policy area. The *Basic Plan* has since been revised every five years. The *First Basic Plan* (1996) called for a drastic increase in government expenditure on R&D, a wider range of competitive research funds and proper care for research infrastructure. The *Second* and *Third Basic Plan*s specified life sciences, information and communication technologies (ICTs), environment and nanotechnology/materials science as being the four priority areas for resource allocation, while also emphasizing the importance of basic science. Whereas fostering a competitive research environment and university–industry collaboration continued to be a major policy agenda, communicating science to society gained greater importance. Innovation became a keyword for the first time in the *Third Basic Plan*, published in 2006. A review of implementation of the *Third Basic Plan* by the Council for Science and Technology Policy found growing support for young researchers, a higher proportion of female researchers and greater university–industry collaboration but noted that further efforts were necessary in these areas. The review also emphasized the importance of effective Plan–Do–Check–Act mechanisms.

Just as the Council for Science and Technology Policy was putting the final touches to the *Fourth Basic Plan*, the Great East Japan Earthquake struck on 11 March 2011. The triple catastrophe – the earthquake having triggered a tsunami and the Fukushima nuclear disaster – made a tremendous impact on Japanese society. About 20 000 people died or were reported missing, 400 000 houses and buildings were damaged and properties amounting to hundreds of billions of dollars were destroyed. A wide area encompassing towns and farms had to be evacuated after being contaminated by radioactive materials and six nuclear reactors had to be abandoned; all the remaining reactors were halted across the nation, although a few did temporarily resume operations later. A large-scale plan to save electricity was implemented nationwide over the summer of 2011.

The release of the *Fourth Basic Plan* was postponed until August 2011, in order to take these developments into account. The new *Plan* was a radical departure from its predecessors. It no longer identified priority areas for R&D but rather put forward three key issue areas to be addressed: recovery and reconstruction from the disaster, 'green innovation' and 'life innovation.' The *Plan* also specified other priority issues, such as a safe, affluent and better quality of life for the public, strong industrial competitiveness, Japan's contribution to solving global problems and sustaining the national foundations.

Thus, the *Fourth Basic Plan* made a radical transition from discipline-based to issue-driven STI policy.

In June 2013, just months after the Abe government's pledge to revive the economy rapidly, the government introduced a new type of policy document, the *Comprehensive Strategy on STI*, a combination of a longer-term vision and actions of a one-year duration. The *Comprehensive Strategy* enumerated concrete R&D themes in such fields as energy systems, health, next-generation infrastructure and regional development, while at the same time proposing ways of improving the national innovation system. The plan also identified three key directions for STI policy: 'smartization,[1]' 'systemization' and 'globalization.' In June 2014, the government revised the *Comprehensive Strategy*, specifying the following areas as being important cross-cutting technological fields for realizing the strategy's vision: ICTs, nanotechnology and environmental technology.

Getting universities to play a more active role in innovation

Any general document related to STI policy in Japan in the past decade has consistently laid heavy emphasis on innovation and university–industry collaboration. A rationale often put forward is that Japan is doing fairly well in scientific research and technological development but is losing ground in terms of value creation and competing on the world stage. Politicians, government officials and industrial leaders all believe that innovation is the key to recovery from Japan's chronic economic stagnation. They also agree that universities should play a more active role in this endeavour.

By 2010, there were already major laws in place to foster university–industry collaboration. The Japanese version of the 'Bayh-Dole provision'[2], which accorded intellectual property rights resulting from publicly funded R&D to research institutes rather than the government, was first codified in a specific act passed in 1999 then made permanent by the Industrial Technology Enhancement Act, amended in 2007. Meanwhile, the Intellectual Property Basic Act had come into effect in 2003, the year that an ambitious reform of tax exemptions for private firms' R&D expenses was introduced, in particular those expenses relating to their collaboration with universities and national R&D institutes. In 2006, the Basic Act on Education was officially amended to expand the mission of universities beyond education and research to making a contribution to society, which implicitly encompassed industrial and regional development.

Numerous programmes were launched within these legal frameworks to foster university–industry collaboration. Some aimed at creating large centres for university–industry research collaboration on varied themes, whereas others supported the creation of university start-ups. There were also programmes to strengthen existing intra-university centres for liaising with industry, supporting university research that responded to specific industrial demands and fostering and deploying co-ordinators at universities. The government also created a series of regional clusters in 2000, although many of these were abolished between 2009 and 2012 after the government decided to terminate innumerable programmes in a hasty effort to cut public spending.

Such a broad range of government support has led to persistent growth in university–industry collaboration in Japan in the past five years. Compared with the preceding five years, however, growth has slowed. In particular, the number of new university start-ups has dropped sharply from a peak of 252 in 2004 to just 52 in 2013 (Table 24.2). In part, this trend reflects the maturation of university–industry relationships in Japan but it may also imply a loss of momentum in public policy initiatives in recent years.

Support for high-risk, high-impact R&D

Nonetheless, the Japanese government remains convinced that promoting innovation through university–industry collaboration is vital for the nation's growth strategy. It has thus recently launched a series of new schemes. In 2012, the government decided to invest in four major universities which would then establish their own funds to invest in new university start-ups jointly with financial institutions, private firms or other partners. When such endeavours yield a profit, part of the profit is returned to the national treasury.

1. Smartization is a term underlying such concepts as 'smart grid' and 'smart city.'

2. The Bayh-Dole Act (officially The Patent and Trademark Law Amendments Act) of 1980 authorized US universities and businesses to commercialize their federally funded inventions.

Table 24.2: **Collaboration between universities and industry in Japan, 2008 and 2013**

Year	Number of joint research projects	Amount of money received by universities in joint research projects (¥ millions)	Number of contract research projects	Amount of money received by universities via contract research projects (¥ millions)	Number of new university start-ups
2008	17 638	43 824	19 201	170 019	90
2013	21 336	51 666	22 212	169 071	52

Note: Here, universities include technical colleges and inter-university research institutes.

Source: UNESCO Institute for Statistics, April 2015

In 2014, a new large programme was launched to support high-risk, high-impact R&D, entitled Impulsing Paradigm Change through disruptive Technologies (ImPACT). This scheme is in many ways similar to that of the US Defense Advanced Research Project Agency. Programme managers have been given considerable discretion and flexibility in assembling teams and directing their efforts.

Another major scheme that got under way in 2014 is the Cross-ministerial Strategic Innovation Promotion (SIP) programme. In order to overcome interministerial barriers, the Council for Science, Technology and Innovation[3] directly administers this programme, promoting all stages of R&D which address key socio-economic challenges for Japan, such as infrastructure management, resilient disaster prevention and agriculture.

These new funding schemes reflect the growing recognition among Japanese policy-makers of the need to finance the entire value chain. The Japanese government is hoping that these new schemes will give rise to groundbreaking innovation that will solve social problems and, at the same time, boost the Japanese economy in the way envisioned by the Abe cabinet.

A boost for renewable energy and clean technology

Historically, Japan has made heavy investments in energy and environmental technology. With few natural resources to speak of, it has launched many national projects since the 1970s to develop both renewable and nuclear energy. Japan had the largest share of solar power generation in the world until the mid-2000s, when it was rapidly overtaken by Germany and China.

After the Great East Japan Earthquake of March 2011, Japan decided to place renewed emphasis on the development and use of renewable energy, particularly since the country's entire network of nuclear reactors was at a standstill by May 2012, with no clear prospect of their starting up again. In July 2012, the government introduced a feed-in tariff, a system which mandates utilities to purchase electricity from renewable energy producers at fixed prices. Relevant deregulation, tax reductions and financial assistance have also encouraged private investment in renewable energy. As a result, the market for solar power has quickly expanded, while the cost of solar electricity has steadily dropped. The share of renewable energy (excluding hydroelectric power) in Japan's total electricity generation rose from 1.0% in 2008 to 2.2% in 2013. It is expected that existing government policies will further enlarge the market for renewable energy.

3. Formerly the Council for Science and Technology Policy, it was strengthened and renamed in 2014.

Japanese industry has been a slow-starter in aeronautics but, since 2003, the Ministry of the Economy, Trade and Industry has been subsidizing an undertaking by Mitsubishi Heavy Industries to develop a jet airliner which it hopes will conquer the global market, thanks to its high fuel efficiency, low environmental impact and minimal noise (Box 24.1).

A disaffection for academic careers

As in many other nations, young Japanese PhD-holders have been finding it difficult to obtain permanent positions in universities or research institutes. The number of doctoral students is on the decline, with many master's students not daring to embark on a seemingly unrewarding career in research.

In response, the Japanese government has taken a series of measures since 2006 to diversify the career paths of young researchers. There have been schemes to promote university–industry exchanges, subsidize internships and develop training programmes to give PhD candidates broader prospects and skills. The government has also promoted curricular reform of doctoral programmes to produce graduates who can more readily adapt to the non-academic environment. In 2011, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) initiated a large-scale Programme for Leading Graduate Schools; this programme has funded the ambitious reform of graduate programmes engaged by universities to stimulate creativity and provide broad-based skills, in order to incubate global leaders in industry, academia and government.

At the same time, the government has taken steps to reform universities' personnel systems. In 2006, the government began subsidizing the introduction of a tenure–track system at university, which had traditionally been absent from Japanese academia. The subsidy was expanded in 2011. The concept of university research administrator (URA) was also officially introduced in 2011. URAs perform a wide range of duties, such as analysing their own institution's strengths, formulating strategies to acquire R&D funding, managing R&D funding, handling issues related to intellectual property rights and maintaining external relations. However, in some universities, URAs are still regarded as being no more than support staff for researchers. It may take some time for the specificity of URAs to be duly recognized in Japanese universities.

Falling student rolls may prompt radical reform

A powerful trend in higher education in recent years has been the emphasis on global human resources, or in other words, people who have no difficulty in working transnationally. Traditionally, the Japanese have been conscious that international interaction is not their strong point, largely due to their poor English. At the turn of the

Box 24.1: The Mitsubishi Regional Jet

The Mitsubishi Regional Jet is the first jet airliner to be designed and produced in Japan. Its official rollout took place on 18 October 2014 and its maiden flight is scheduled for 2015. The first deliveries should follow in 2017. Hundreds of orders have already been received from domestic and foreign airlines.

The jet's main manufacturers are Mitsubishi Heavy Industries and its subsidiary Mitsubishi Aircraft Corporation, established in 2008. Different models of the jet will carry 70–90 passengers with flight ranges of 1 500–3 400 km.

The Japanese aerospace industry has been a slow-starter in aeronautics. Aircraft production was banned in Japan for seven years after the end of the Second World War. After the ban was lifted, research on aerospace technology gradually took off, thanks to the entrepreneurial efforts of a group of researchers at the University of Tokyo and other academic, industrial and government institutions.

Over the following decades, plans to develop and produce aeroplanes were repeatedly thwarted. A semi-public corporation created in 1959 began developing a medium-sized turboprop airliner YS-11 and actually produced 182 airframes before being disbanded and absorbed into Mitsubishi Heavy Industries in 1982 after accumulating losses. Heavily subsidized and controlled by the Ministry of International Trade and Industry (renamed the Ministry of the Economy, Trade and Industry in 2001), the corporation lacked the requisite flexibility to adapt to the changing international market.

Although the ministry consistently strived to promote the Japanese aerospace industry from the 1970s onwards, it was not easy for Japanese manufacturers to realize their plans to develop new aircraft. For a long time, they remained subcontractors to American and European firms. It was only in 2003 that Mitsubishi Heavy Industries began developing a medium-sized jet airliner, a year after the ministry announced that it would subsidize such an undertaking. The original plan was to make a maiden flight by 2007 but this proved overly optimistic.

The initial budget of ¥ 50 billion has since grown to around ¥ 200 billion but, thanks to the tenacious efforts of Mitsubishi and other manufacturers, the Mitsubish Regional Jet boasts high fuel efficiency, a low environmental impact and little noise. Japan's traditional strength in carbon fibre, which has been widely adopted in aeroplanes all over the world, has also been fully incorporated in the jet. Hopefully, these technological merits will have strong consumer appeal in the global market.

Source: compiled by authors

century, however, virtually all businesses were finding it increasingly difficult to operate within Japan's closed market. In response, MEXT initiated a major project in 2012 for the Promotion of Global Human Resource Development, which was expanded in 2014 into the Top Global University Project. These projects provided universities with generous subsidies to produce specialists who would feel comfortable working transnationally. Such government projects aside, Japanese universities are themselves making it a priority to educate students in today's global context and to enrol international students. By 2013, 15.5% of all graduate students (255 386) were of foreign origin (39 641). The great majority (88%) of international graduates[4] were Asian (34 840), including 22 701 from China and 2 853 from the Republic of Korea.

Arguably the most fundamental challenge facing Japanese universities is the shrinking 18 year-old population. Since peaking at 2 049 471 in 1992, the number of 18 year-olds has almost halved to 1 180 838 (2014). The number of university entrants has nevertheless risen, owing to the surge in the proportion of young Japanese attending university: 26.4% in 1992 and 51.5% in 2014 (Figure 24.1). However, most stakeholders see signs of saturation; they share the view that a radical reform of the nation's university system is imminent.

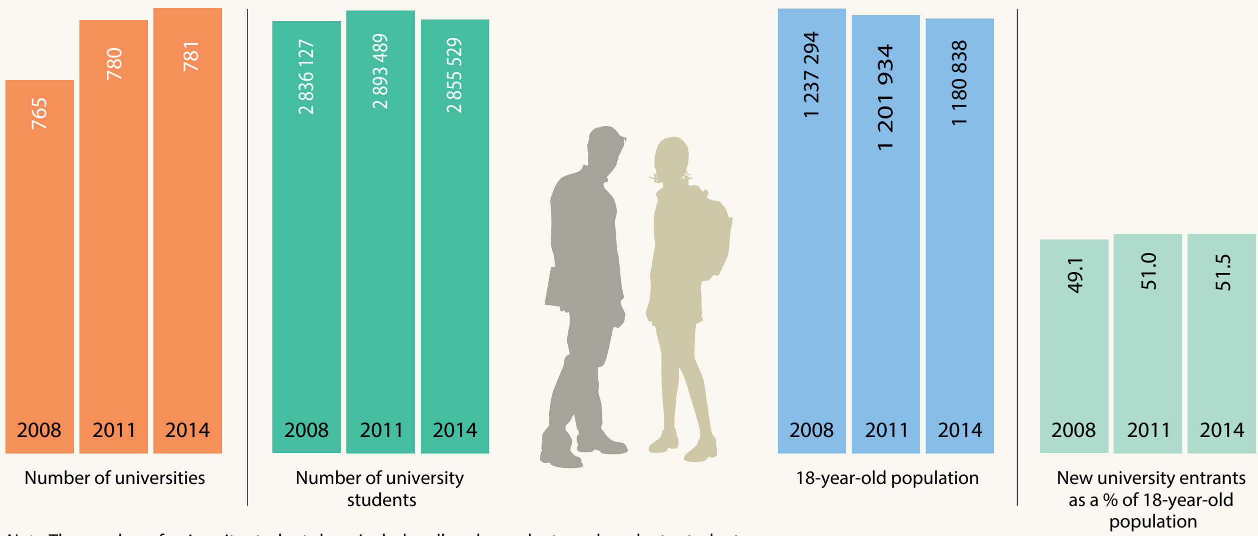
The number of universities in Japan had climbed steadily until recently. As of 2014, there were 86 national universities, 92 other public universities and 603 private universities. This total (781) is quite large by international standards. About half of private universities are now unable to fill their quota, suggesting that a massive consolidation and merger may take place in the near future.

An historic reform which stratifies universities

A government-led structural reform of national universities is already under way. Ever since these were semi-privatized in 2004 and renamed national university corporations, their regular government funding has been cut by roughly 1% each year. National universities were expected to help themselves by obtaining more research grants, more private-sector funding and more donations. Not all of them have managed to adapt well to this new environment, however;

4. Others came from Viet Nam (1 333) and Malaysia (685). Among non-Asian students, 1 959 were European, 872 African, 747 from the Middle East, 649 from Latin America (649) and 424 from North America.

Figure 24.1: **Number of universities and university students in Japan, 2008, 2011 and 2014**



Note: The number of university students here includes all undergraduate and graduate students.

Source: MEXT (2014b, 2014c)

only a handful have remained healthy, the others having suffered from shrinking funding. In light of this situation, the government has been urging universities since 2012 to initiate reforms and to redefine their own missions to make the most of their unique strengths. As an incentive, the government is providing universities willing to engage in reform with a range of subsidies.

The universities' efforts alone have not sufficed, however. In November 2013, MEXT announced the *National University Reform Plan*, in which the ministry suggested that each national university choose one of three directions; it could become a world-class centre for education and research, a national centre for education and research or a core centre for regional revitalization. In July 2014, MEXT made it clear that funding for national universities would also be reformed; under the new scheme, three types of universities would be evaluated according to different criteria and funding options. This is an epoch-making decision because all national universities in Japan have had the same institutional status up until now. From now on, they will be officially stratified.

Publicly funded R&D institutions are also under reform. Previously, institutions such as the Japan Aerospace Exploration Agency, Japan International Cooperation Agency and Urban Renaissance Agency fell under the same category of independent administrative agencies. In June 2014, a bill was passed which attributes a separate status of national R&D agency to 31 out of 98 agencies. National R&D agencies will be evaluated on a relatively long-term basis (every 5–7 years), compared to other agencies (mostly 3–5 years), to maximize their R&D performance.

Although the Institute of Physical and Chemical Research (RIKEN) and the National Institute of Advanced Industrial Science and Technology (AIST) are currently catalogued as independent administrative agencies, the government was intending to make them special national R&D agencies, a status which would have given them considerable latitude in introducing unique evaluation systems and entitled them to pay exceptionally high salaries to outstanding researchers. The plan has been put on hold, however, following a highly publicized case of misconduct by a RIKEN researcher which shall be evoked again below.

Creating spaces where scientists and the public can meet

In 2001, the second *Basic Plan for Science and Technology* recognized the increasing interdependence between science and society. It underlined the need to strengthen bidirectional communication between science and society, urging researchers in social sciences and humanities to play their part. Since then, a great variety of programmes related to science communication, science cafés, science outreach, science literacy and risk communication have been launched. Graduate programmes in science communication and science journalism have been introduced in several universities and the number of science communicators has clearly increased. Since 2006, the Japan Science and Technology Agency has been holding an annual festival called Science Agora to provide a place for scientists and the general public to meet. Science Agora's mandate was expanded in 2014 to include debate on critical social issues related to science and technology.

Scientific advice has come to the fore since the triple catastrophe

The importance of maintaining a dialogue between scientists and policy-makers has been recognized more recently. The issue of scientific advice came to the fore after the Great East Japan Earthquake of March 2011. There was a widespread perception that the government was unable to mobilize scientific knowledge to cope with the triple catastrophe. A series of symposia were held to discuss the role of scientific advice in policy-making and the idea was tabled of appointing science advisors to the prime minister and other ministers, although this idea has not materialized yet. Meanwhile, the Science Council of Japan (the Japanese Academy of Sciences) revised its Code of Conduct for Scientists in January 2013, adding a new section on scientific advice. A stronger commitment to this issue on the part of policy-makers will be necessary for Japan to participate actively in the rapidly evolving international discussion on this topic.

In 2011, the government launched a programme called Science for RE-designing Science, Technology and Innovation Policy (SciREX). The purpose is to establish a system which reflects scientific evidence[5] more robustly in STI policy. The SciREX programme supports several research and education centres within universities, issues grants to researchers in relevant fields, and promote the construction of the relevant evidence base. The many researchers in social sciences and humanities involved in this programme are training specialists in this new field and publishing their findings on such themes as science-based innovation, STI and economic growth, policy-making processes, the social implication of S&T and the evaluation of R&D.

While SciREX is mainly concerned with evidence-based STI policy, science and technology can also inform other policy fields, such as environmental policy and health policy ('science for policy,' as opposed to 'policy for science'). In these fields, policy-makers rely heavily on advice put forward by scientists in various formats because solid policy-making is impossible without specialized knowledge of relevant phenomena.

Despite the obvious virtues of scientific advice for policy-making, the relationship between the two is not always straightforward. Scientific advice can reflect uncertainties and scientists may express divergent opinions. Scientific advisors may be affected by a conflict of interest, or subject to pressure from policy-makers. For their part, policy-makers may select scientific advisors arbitrarily or interpret scientific advice in biased ways. The question of scientific advice has thus become an important topic for discussion in many Western nations and international bodies like the OECD.

Research misconduct has undermined public trust

Research integrity is at the heart of public trust in science. In Japan, the number of publicized cases of research misconduct increased markedly during the 2000s, in parallel with shrinking regular funding for universities and the growth in competitive grants. In 2006, the government and the Science Council of Japan respectively established guidelines on research misconduct but these have not reversed the trend. Since 2010, there has been a spate of reported cases of large-scale research misconduct and misuse of research funds.

In 2014, an extremely serious and highly conspicuous case of research misconduct was exposed in Japan. On 28 January, a 30-year old female researcher and her senior colleagues held a sensational press conference at which they announced that their papers on the creation of Stimulus-Triggered Acquisition of Pluripotent (STAP) cells were being published in *Nature* the next day. This stunning scientific breakthrough received extensive media coverage and the young researcher became a star overnight. Soon after, however, questions were raised in cyberspace about indications of manipulated figures and plagiarized texts in the papers. Her employer, RIKEN, subsequently confirmed her misconduct on 1 April. Although she resisted for a long time and never publicly admitted her misdeeds, she did resign from RIKEN after the institute's investigative committee conclusively rejected the validity of the papers on 26 December, asserting that the STAP cells were in fact another well-known type of pluripotent cell known as embryonic stem cells.

The saga was closely followed by the Japanese population; it seriously undermined public perception of the validity of science in Japan. The case also spurred a wider round of public debate on S&T policy in general. For example, after questions were raised about the young researcher's doctoral thesis, her alma mater, Waseda University, carried out an investigation and decided to cancel her degree with a one-year suspension to give her time to make the necessary corrections. In parallel, the university began investigating other theses originating from her former department. Aside from the problem of quality assurance of degrees, many other issues came to the fore, such as the intense competition among researchers and institutions and the inadequate training of young researchers. In response to this serious, highly publicized case, MEXT revised its guidelines on research misconduct in 2014. These guidelines alone will not suffice, however, to solve the underlying problems.

5. understood as encompassing not only information and knowledge from natural sciences but also from economics, political science and other social sciences, as well as humanities

TRENDS IN R&D

Low government spending on R&D

Japan's gross domestic expenditure on R&D (GERD) had grown consistently until 2007, before plunging suddenly by nearly 10% in the aftermath of the US subprime crisis. Only in 2013 did GERD rebound, mainly due to the recovery of the global economy (Table 24.3). Japan's GERD is closely linked to the nation's GDP, so the drop in GDP in recent years has allowed Japan's GERD/GDP ratio to remain high by international standards.

Government expenditure on R&D increased over the same period but appearances can be deceptive. Japan's R&D budget fluctuates each year owing to the irregular, yet frequent approval of supplementary budgets, especially in the wake of the Great East Japan Earthquake. If we look at the long-term trend, Japan's stagnating government R&D expenditure reflects the extremely tight fiscal situation. By any measurement, though, the ratio of government spending on R&D to GDP has remained low by international standards; the *Fourth Basic Plan* (2011) fixes the target of raising this ratio to 1% or more of GDP by 2015. The *Plan* contains a second ambitious target, that of raising GERD to 4% of GDP by 2020.

The overall structure of Japan's government R&D expenditure has gradually changed. As we said earlier, regular funding of national universities has declined consistently for more than a decade by roughly 1% a year. In parallel, the amount of competitive grants and project funding have increased. In particular, there has been a proliferation recently of multi-purpose, large-scale grants that do not target individual researchers but rather the universities themselves; these grants are not destined purely to fund university research and/or education *per se;* they also mandate universities to conduct systemic reforms, such as the revision of curricula, introduction of tenure–track systems, diversification of researchers' career paths, promotion of female researchers, internationalization of educational and research activities and moves to improve university governance.

As many universities are now in serious want of funding, they spend an extraordinary amount of time and effort applying for these large institutional grants. There is growing recognition, however, of the side-effects of spending so much time on applications, administration and project evaluation: a heavy burden on both academic and administrative staff; short-cycle evaluations can discourage research and education from longer-term viewpoints and; it is often hard to maintain project activities, teams and infrastructure once the projects end. How to strike the best balance between regular and project funding is thus becoming an important policy issue in Japan.

The most remarkable trend in industrial spending on R&D has been the substantial cutback in ICTs (Figure 24.2). Even the Nippon Telegraph and Telephone Corporation, which had historically played a key role as a formerly public organization, was forced to trim its R&D spending. Most other industries maintained more or less the same level of R&D expenditure between 2008 and 2013. Car manufacturers coped relatively well, for instance, Toyota even coming out on top for global car sales between 2012 and 2014. Hardest hit after the global recession of 2008–2009 were Japanese electric manufacturers, including major players such as Panasonic, Sony and NEC, which cut back their R&D spending drastically in the face of severe financial difficulties; compared with manufacturers in other fields, their recovery has been slow and unsteady. It remains to be seen whether the economic stimuli introduced through Abenomics since 2013 will reverse this trend.

Cutbacks in industry have affected research staff

The number of researchers in Japan grew steadily until 2009, when private enterprises began cutting back their research[6] spending. By 2013, there were 892 406 researchers in Japan (by head count), according to the OECD, which translated into 660 489 full-time equivalents (FTE). Despite the drop since 2009, the number of researchers per 10 000 inhabitants remains among the highest in the world (Figure 24.3).

6. Some enterprises stopped hiring, others laid off staff or re-assigned them to non-research positions.

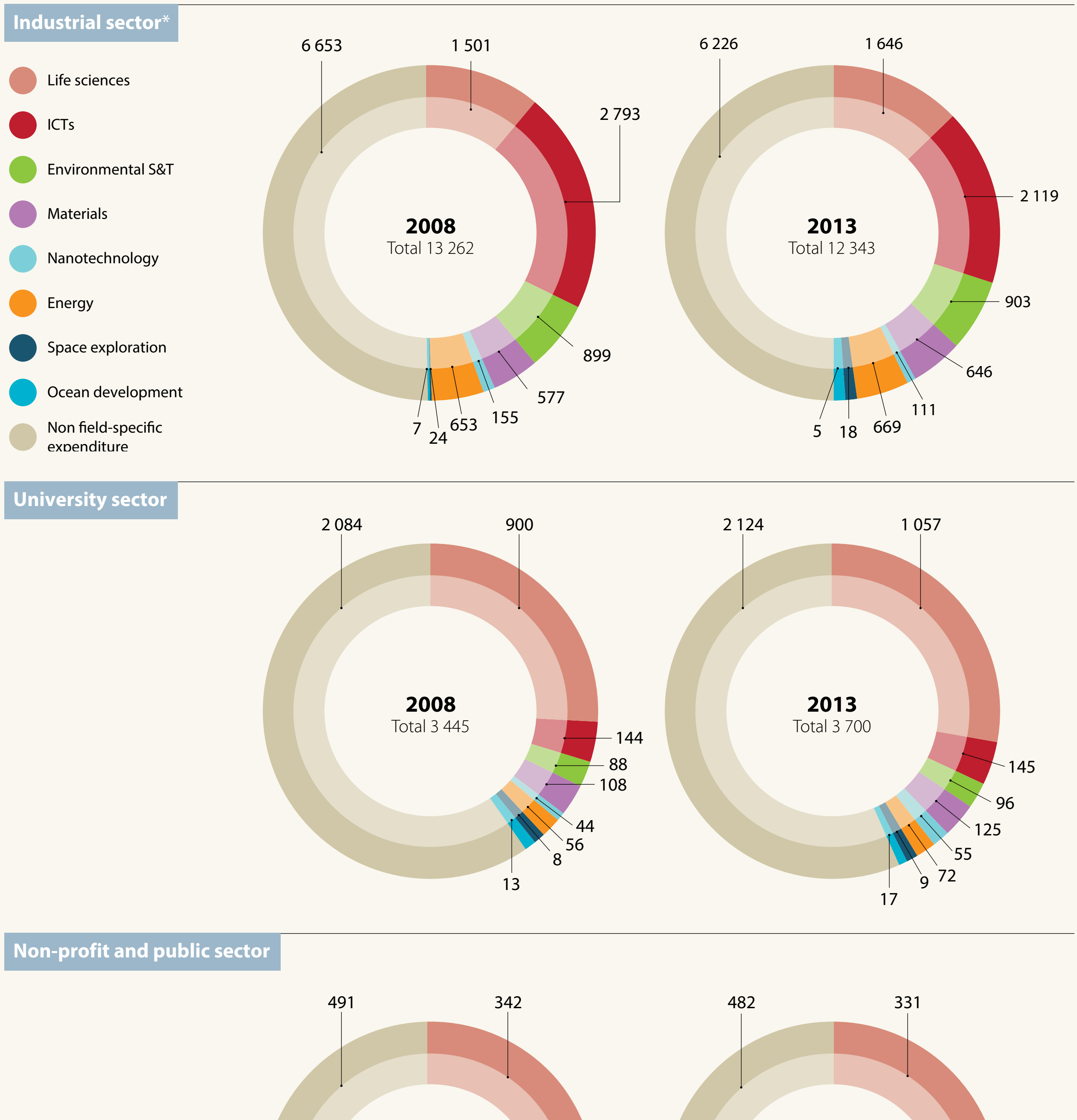
Table 24.3: **Trends in Japanese GERD, 2008–2013**

Year	GERD (¥ billion)	GERD/GDP ratio (%)	Government expenditure on R&D (GOVERD) (¥ billion)	GOVERD/GDP ratio (%)	GOVERD plus higher education expenditure on R&D/ GDP ratio (%)
2008	17 377	3.47	1 447	0.29	0.69
2009	15 818	3.36	1 458	0.31	0.76
2010	15 696	3.25	1 417	0.29	0.71
2011	15 945	3.38	1 335	0.28	0.73
2012	15 884	3.35	1 369	0.29	0.74
2013	16 680	3.49	1 529	0.32	0.79

Source: UNESCO Institute for Statistics, April 2015

Figure 24.2: **R&D expenditure in Japan by field, 2008 and 2013**

In ¥ billions



* business enterprises with capital of ¥ 100 million or more

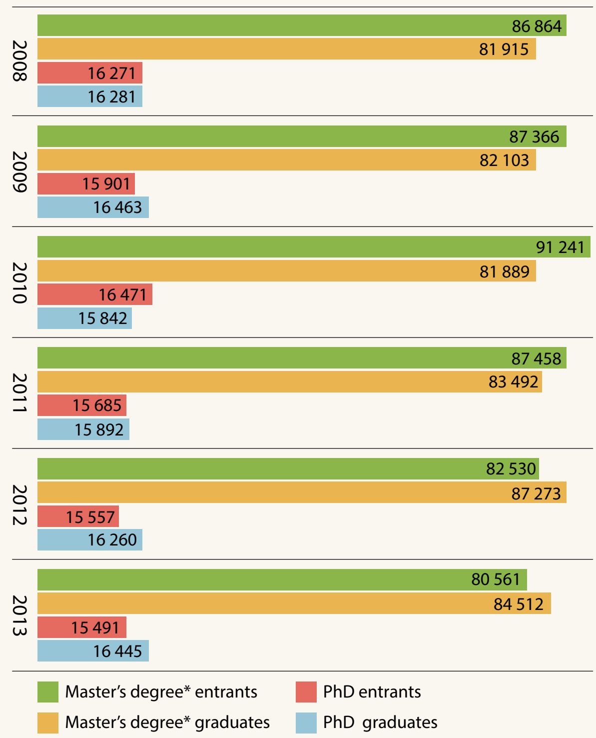
Note: The automotive industry falls under the non field-specific expenditure and electronics and electric components are partly covered by ICTs.

Source: Statistics Bureau (2009, 2014) *Survey of Research and Development*

Figure 24.3: Number of researchers (HC) in Japan, 2008 and 2013

Source: Statistics Bureau (2009, 2014) *Survey of Research and Development*

Figure 24.4: Trends in master's and PhD programmes in Japan, 2008–2013



* includes professional degree courses

Source: MEXT (2013, 2014c) *Statistical Abstract of Education, Science and Culture*

The number of master's students grew steadily until 2010 when the curve inversed (Figure 24.4). The rise can largely be attributed to the financial crisis from 2008 onwards, when graduates fresh out of university enrolled in graduate schools after giving up hope of finding a job. The drop in enrolment in a master's degree can be partly explained by the growing disappointment in law schools, which were first instituted in 2004 to train a mass of lawyers with diverse backgrounds but have actually produced a mass of jobless lawyers. It might also reflect university students' general scepticism as to the utility of the master's degree. Many master's students also appear to be discouraged from postgraduate study by the prospect of an uncertain career path. The number of new PhD students has also been dropping since peaking at 18 232 in 2003.

Research: more feminine and more international

One in seven Japanese researchers was a woman in 2013 (14.6%). Although this is an improvement on 2008 (13.0%), Japan still has the lowest proportion of women researchers of any member of the Organisation for Economic Co-operation and Development (OECD). The Japanese government is determined to improve this ratio. The *Third* (2006) *and Fourth* (2011) *Basic Plans for Science and Technology* both fixed a goal of a 25% ratio of women: 20% of all researchers in science, 15% in engineering and 30% in agriculture, medicine, dental and pharmaceutical research (Figure 24.5). These percentages are based on the current share of doctoral students in these fields. In 2006, a fellowship scheme was launched for women researchers returning to work after maternity leave. Moreover, given that the ratio of female researchers has been embedded in the assessment criteria of various institutional reviews, many universities now explicitly favour the recruitment of women researchers. As the Abe cabinet strongly advocates a greater social participation by women, it is quite likely that the rise in female researchers will accelerate.

The number of foreign researchers is also gradually rising. In the university sector, there were 5 875 foreign full-time teaching staff (or 3.5% of the total) in 2008, compared to 7 075 (4.0%) in 2013. Since this ratio remains fairly low, the government has been taking measures to internationalize Japanese universities. The selection criteria for most large university grants now take into account the proportion of foreigners and women among teaching staff and researchers.

Scientific productivity a casualty of multitasking

Japan's world share of scientific publications peaked in the late 1990s and has been sliding ever since. The nation was still producing 7.9% of the world's scientific papers in 2007, according to the Web of Science, but its share had receded to

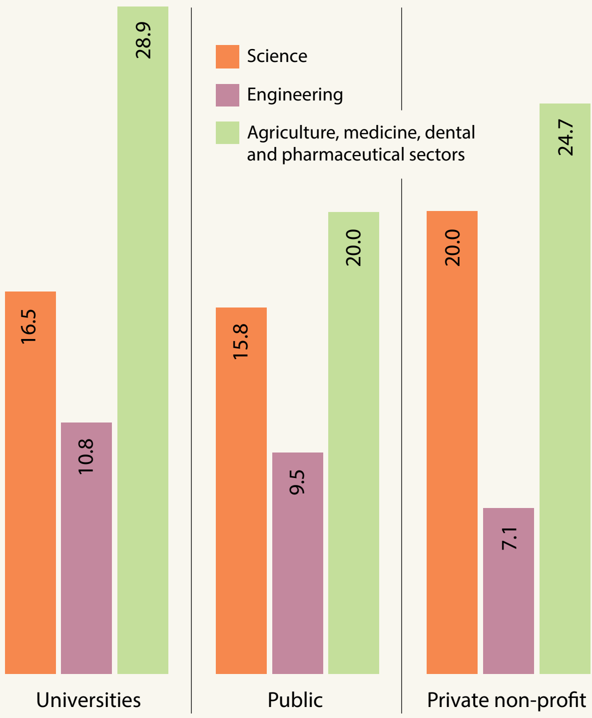
5.8% by 2014. Although this is partly due to China's continuing growth, Japan's poor performance is extraordinary: the world produced 31.6% more papers in 2014 than in 2007 but Japan's production declined by 3.5% over the same period.

One explanation may lie in the meagre growth in Japanese university spending on R&D over the same period, just 1.3% in constant prices, according to the UNESCO Institute for Statistics. The shrinking amount of university researchers' time reserved for research may also be to blame. As we have seen, there has been a modest increase in the number of university researchers in Japan in recent years but the use of their time has changed considerably: each researcher spent an average of 1 142 hours on research in 2008 but only 900 hours in 2013 (Figure 24.6). This worrying 21% drop can be partly accounted for by the decrease in the average number of hours worked by university researchers, which were cut back from 2 920 to 2 573 over the same period. What is certain is that the time allocated to research has been curtailed far more sharply than the time devoted to teaching and other activities; researchers face an array of unavoidable tasks these days: preparing classes in English as well as in Japanese, writing syllabi for all their classes, mentoring students beyond the academic setting, recruiting prospective students, setting up highly diversified and complicated enrollment processes, adapting to increasingly stringent environmental, safety and security requirements, etc..

The decline in publications by Japanese researchers might also be related to changes in the nature of public R&D funding. More and more grants to individual researchers as well as universities are becoming innovation-oriented, and just writing academic papers is no longer regarded as inadequate. Whereas innovation-oriented R&D activities also lead to academic papers, Japanese researchers' effort is now possibly less concentrated on producing papers *per se*. At the same time, there are indications that decrease in private R&D funding has brought about a drop of publications by researchers in the private sector.

The downward trend in Japan's publication record is visible in all fields of science (Figure 24.7). Even in chemistry, materials science and physics, fields where Japan used to have a certain presence, its world share has dropped considerably. This is somewhat ironic, considering that a growing number of Japanese scientists have been internationally recognized in recent years for their truly outstanding work. Since the beginning of the century, 15 Japanese scientists (two of whom have become US citizens) have received Nobel prizes (Box 24.2). In point of fact, most of their achievements were made decades ago. This begs the question of whether Japan still retains the institutional and cultural environment that gives rise to such creative work. In the current climate, it will be a real challenge to realize the *Fourth Basic Plan's* target of positioning 100 institutions among the world's top 50 for the citation of research papers in specific fields by 2015.

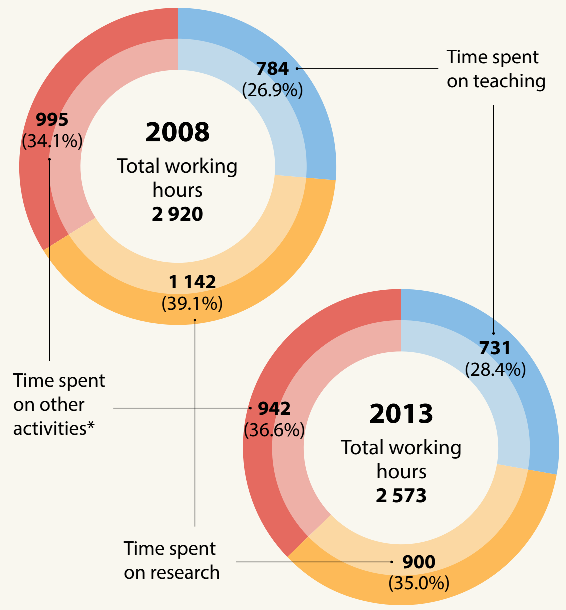
Figure 24.5: **Share of female researchers in Japan by sector and employer, 2013 (%)**



Note: Data are unavailable for the business enterprise sector.

Source: Statistics Bureau (2014) Survey of Research and Development.

Figure 24.6: **Breakdown of working hours of Japanese university researchers, 2008 and 2013**



* Time spent on university administration, services to society such as clinical activities, etc

Source: MEXT (2009, 2014d) *Survey on FTE data for Researchers in Higher Education Institutions*

Figure 24.7: **Scientific publication trends in Japan, 2005–2014**

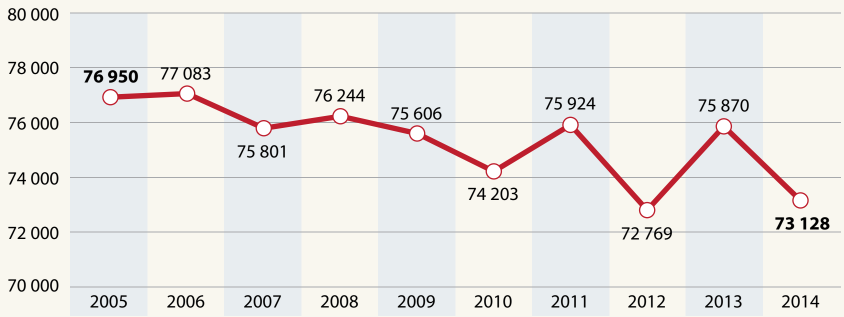
The number of Japanese publications has declined since 2005

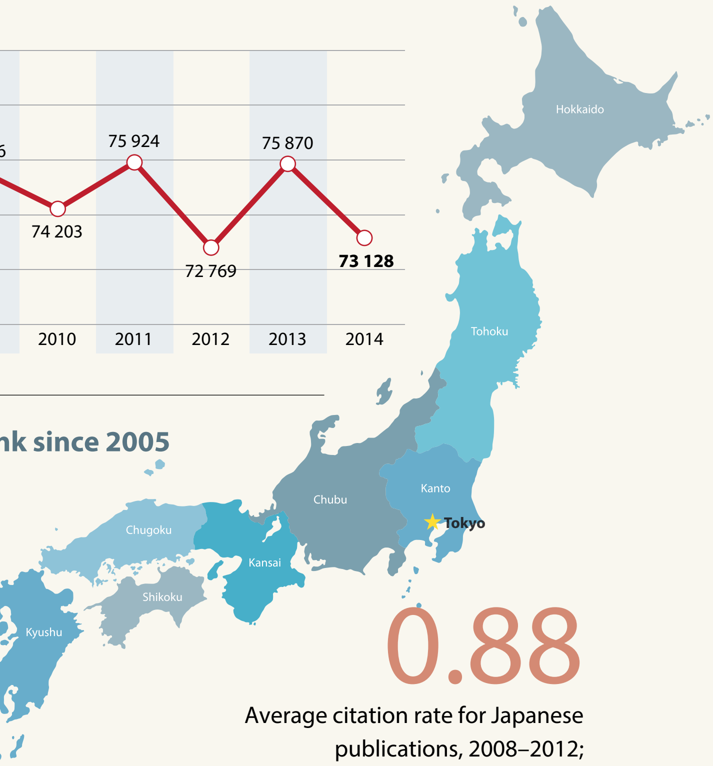
606

Publications per million inhabitants in 2005

576

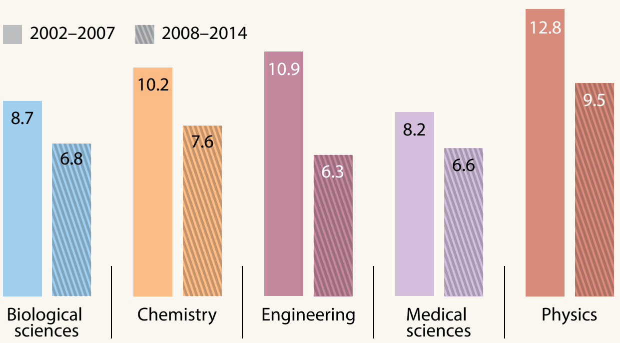
Publications per million inhabitants in 2014





Japan's world share of scientific publications has shrunk since 2005

World share of Japanese articles by field (%)



0.88

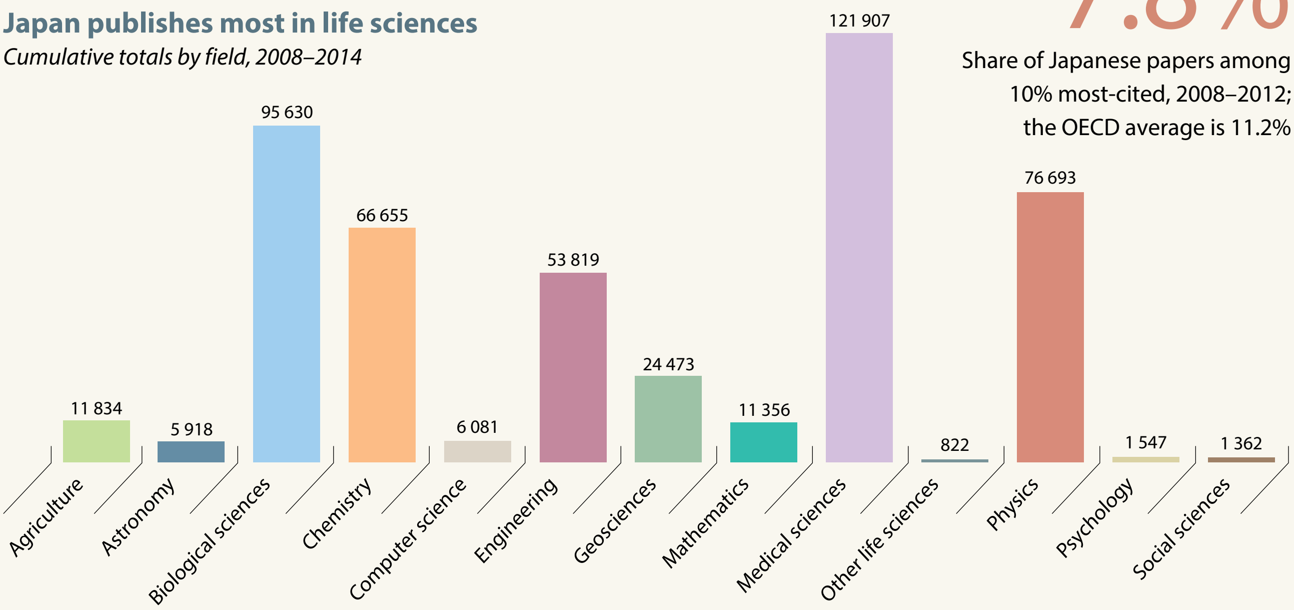
Average citation rate for Japanese publications, 2008–2012; the OECD average is 1.08

7.8%

Share of Japanese papers among 10% most-cited, 2008–2012; the OECD average is 11.2%

Japan publishes most in life sciences

Cumulative totals by field, 2008–2014



Note: Excludes 45 647 unclassified articles

27.1%

Share of Japanese papers with foreign co-authors, 2008–2014; the OECD average is 29.0%

Japan's top partners are the USA and China

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Japan	USA (50 506)	China (26 053)	Germany (15 943)	UK (14 796)	Korea, Rep. (12 108)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix, November 2014; for Japan's world share of publications: NISTEP (2009, 2014) *Indicators of Science and Technology*

Box 24.2: Why the increase in Japanese Nobel laureates since 2000?

Every year, Japanese people excitedly await the announcement from Sweden of the year's Nobel laureates. If Japanese scientists are named, great celebration by the media and the public follows.

Between 1901 and 1999, the public would have had to be extremely patient: just five Japanese scientists received the prestigious award over this entire period. Since 2000, on the other hand, 16 Japanese scientists have been distinguished, including two who have become US citizens.

This does not necessarily mean that the research environment in Japan has improved overnight, since much of the laureates' work was done before the 1980s. However, public and private R&D funding did make a difference in some cases. The work of Shinya Yamanaka, for example, received ample funding in the 2000s from the Japan Society for the Promotion of Science and the Japan Science and Technology Agency. Yamanaka was recompensed (Nobel Prize for Physiology or Medicine, 2012) for his discovery of induced pluripotent stem cells. As for Shuji Nakamura (Nobel Prize for Physics, 2014), he invented efficient blue light-emitting diodes (LED) in the 1990s, thanks to the generous support of his company, Nichia Corporation.

What other factors could explain the increase in Japanese Nobel laureates? It would appear that the focus of the prize has changed. Although the selection process is not disclosed, the social impact of research seems to have been carrying more weight in recent years. All six Nobel prizes awarded to Japanese scientists since 2010 are for discoveries which have had a demonstrable impact on society, even though three Japanese physicists (Yoichiro Nambu, Toshihide Maskawa and Makoto Kobayashi) received the prize in 2008 for their purely theoretical work in particle physics.

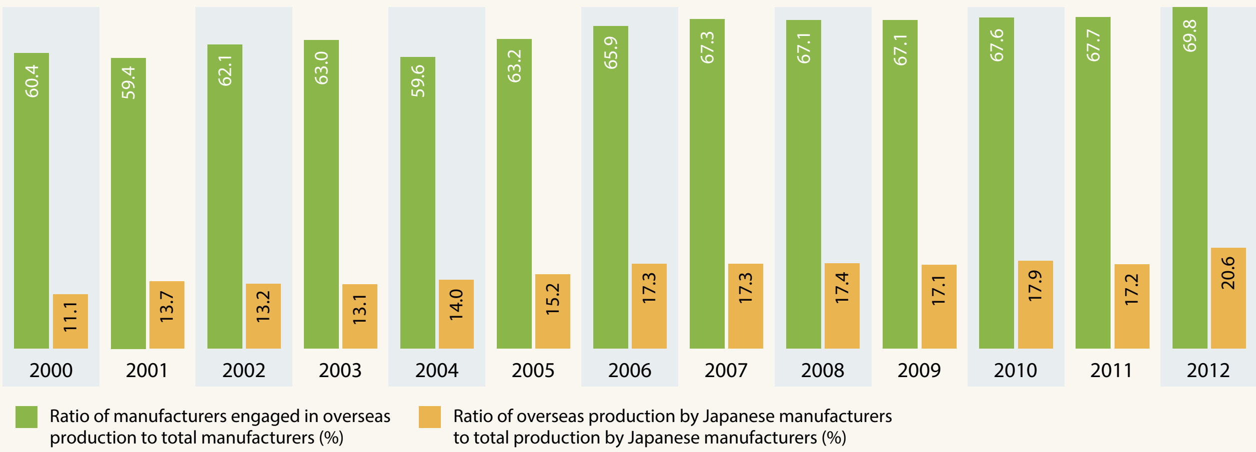
If the Nobel Prize Committee is indeed giving greater recognition to the social impact of research, this could well be a reflection of the changing mindset of the global academic community. The *Declaration on Science and the Use of Scientific Knowledge* and *Science Agenda: Framework for Action* from the World Conference on Science in 1999 may well be the harbinger of this change. Organized in Budapest (Hungary) by UNESCO and the International Council for Science, the World Conference on Science produced documents which explicitly stressed the importance of 'science in society and science for society,' as well as 'science for knowledge.'

Source: compiled by authors

Patents: aiming for quality over quantity

The number of patent applications to the Japan Patent Office (JPO) has been declining since 2001. Many factors seem to have contributed to this phenomenon. In the past decade, many firms have refrained from applying for large quantities of patents, instead focusing their efforts on obtaining high-quality patents. This is partly because of the steep rise in examination fees charged by the JPO since 2004. After the global crisis in particular, Japanese firms could no longer afford to spend as much as before on patent applications. They have also come to lay more emphasis on applying to foreign patent offices, reducing the relative importance of domestic patents. In addition, years of an overappreciated yen and a shrinking Japanese market, have spurred many firms to move their R&D and manufacturing centres abroad; as a result, they now feel less inclined to file many of their patents in Japan (Figure 24.8).

Figure 24.8: **Overseas production by Japanese manufacturers, 2000-2012**



Source: Cabinet Office (2008–2013) *Annual Survey of Corporate Behaviour*

Table 24.4: **Patent activities in Japan, 2008 and 2013**

	Patent applications	Granted patents	Examination time (months)	PCT international applications
2008	391 002	159 961	29	28 027
2013	328 436	260 046	11	43 075

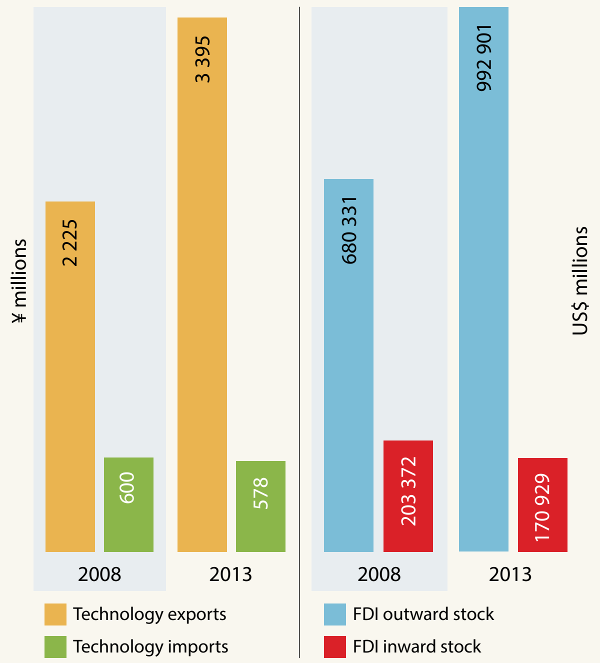
PCT = Patent Cooperation Treaty

Source: Japan Patent Office (2013, 2014) *Annual Report of Patent Administration*

The JPO had actually intended for the number of patent applications in Japan to drop, in order to solve the chronic problem of long waiting times for patent applications to be examined. The first Intellectual Property Promotion Programme had been established in 2004 to reduce the waiting time from 26 months to 11 months by 2013. JPO encouraged private firms to select only their best candidates for patent application; it also raised the number of patent examiners by 50%, mainly through massive hiring of fixed-term officials, and at the same time improved their productivity. In the end, JPO achieved its goal just in time (Table 24.4).

There may be another explanation for the decrease in patent applications: this could be a symptom of Japan's weakening innovative capabilities. Since patent statistics reflect so many different factors, their validity as an indicator of R&D seems less evident than it once did. In today's ever-more globalized world, the very meaning of the national patent system is changing.

Figure 24.9: **Japan's technology trade and FDI stock, 2008 and 2013**



Source: Statistics Bureau (2014); UNCTAD (2009, 2014) *World Investment Report*

TRENDS IN GLOBAL ENGAGEMENT

Strong on technology but less competitive than before

In recent years, Japan's economic relationship with the world has fundamentally changed. In 2011, the country recorded a trade deficit for the first time since 1980. This was partly due to a decrease in exports, combined with a rise in oil and natural gas imports following the 2011 triple catastrophe in the Tohoku area and the subsequent halting of nuclear power plants. The trade deficit did not turn out to be a temporary phenomenon, however. It has become chronic, fuelled by the weak competitiveness of Japanese manufacturers in the global market, the transfer of their factories overseas and high prices for oil and other natural commodities. Even though Japan's current account is still in the black, its industrial fabric is definitely less competitive than it used to be.

That is not to say that Japan's technological strength has waned. For example, technology exports grew by more than 53% between 2008 and 2013, whereas technology imports remained roughly constant over the same period. Japan's outward FDI stocks swelled by 46%, even as inward FDI stocks shrank by 16%. Japan has thus been increasingly active in transferring technology and investing abroad. The fact that FDI inflows remain low in comparison with other nations has become a source of concern, however, for it means that Japan is failing to attract foreign investors and introduce foreign business resources. The Japanese government regards FDI inflows as being generally beneficial because they create jobs and boost productivity, while at the same time promoting open innovation and revitalizing the regional economy, which has long suffered from depopulation and ageing.

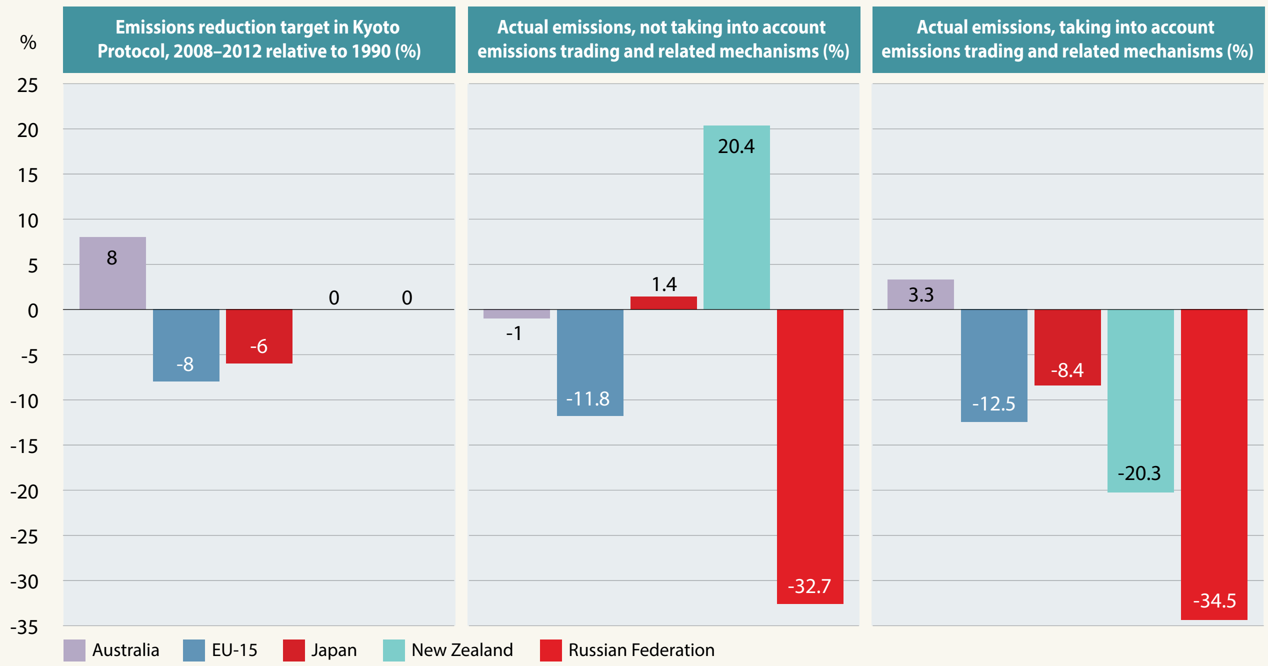
Incentives to attract FDI

The Japanese government has recently taken steps to stimulate FDI inflows (Figure 24.9). A law enacted in November 2012 provides incentives for global corporations to relocate their R&D centres and Asian branches to Japan, such as a reduction in corporate tax and other privileges. Just months later, in June 2013, the Abe Cabinet's *Japan Revitalization Strategy: Japan is Back*, fixed the target of doubling FDI inflows by 2020. To this end, the government designated six National Strategic Special Zones that are expected to become international centres for business and innovation through deregulation. Behind these measures is a sense of crisis that Japan might be losing its attractiveness as a business destination relative to other Asian nations.

Fortunately, there is currently a fertile environment for business. A drastic depreciation of the yen in recent few years has induced many Japanese manufacturers to bring their factories back to Japan, thereby steadily generating jobs. Lower oil prices and corporate tax rates have also fostered this 're-shoring' trend among Japanese firms. Although it is uncertain how long these

Figure 24.10: **Japan's progress towards targets under the Kyoto Protocol, 2012**

Other countries are given for comparison



Source: Greenhouse Gas Inventory Office of Japan, National Institute for Environmental Studies

favourable conditions will last, there are signs that Japanese corporations are also re-evaluating the unique strengths of the business environment in Japan, which include social stability, reliable production infrastructure and a capable labour force.

A commitment to international targets

While aiming for competitiveness, Japan has also been deeply committed to the international agenda for sustainable development. Under the *Kyoto Protocol* of 1997, Japan agreed to reduce its greenhouse gas emissions by 6% over 2008–2012 relative to 1990. Taking into account emissions trading and related mechanisms, Japan has reached this target (Figure 24.10). Ironically, the economic damage caused by the global financial crisis helped Japan to attain this feat. Japan has been reluctant to participate in any new scheme, however, as long as major emitters such as China, the USA and India do not have any substantial duty[7]. In fact, Japanese firms were dissatisfied with the *Kyoto Protocol* because they perceived Japan as already being a low-emitter by the 1990s and felt it would be more difficult for the country to achieve a similar goal than for other countries.

More recently, Japan has eagerly taken part in emerging global frameworks for sustainability. Japan has been an active participant of the Belmont Forum, an association of funding agencies supporting research on earth's environmental changes, ever since its inception in 2009. It has also been one of the drivers behind an ambitious scheme beginning in 2015, Future Earth. This scheme incorporates several global research frameworks for global environmental change and is expected to last for ten years. Japan also hosted the 10th Conference of the Parties to the Convention on Biological Diversity in October 2010. The *Nagoya Protocol* adopted by this conference provides a legal framework for the fair, equitable sharing of benefits arising from the utilization of genetic resources. The conference also adopted 20 *Aichi Biodiversity Targets* for the global community to 2015 and 2020. In accordance with these international agreements, the Japanese government revised its own *National Strategy for Biodiversity* in 2012, specifying detailed targets, action plans and indicators for evaluation[8].

Japan's proactive stance on global engagement is founded on its vision of science diplomacy. Japan considers that its participation in co-operative programmes in science and technology strengthens its diplomatic relations and is therefore in the national interest. In 2008, MEXT and the Ministry of Foreign Affairs launched a joint programme for a Science and Technology Research Partnership for Sustainable Development (SATREPS) with developing countries; collaborative research projects tackle problems in such areas as environment, energy, natural disasters and infectious diseases.

7. China and India did not have specific targets under the *Kyoto Protocol* and the USA was not a signatory.

8. Japan's legal framework in this field consists of the Basic Act on Biodiversity (2008) and the Act on Promotion of Regional Co-operation for Biodiversity (2010).

CONCLUSION

A need for forward-looking policies and a new mindset

Japan has experienced some stark trends since 2010: public and private funding of R&D have barely evolved, fewer students are entering doctoral programmes and the number of scientific publications is declining. These trends have been shaped by the current macro-socioeconomic context: an ageing population, demographic decline, sluggish economic growth and a burgeoning national debt burden.

Over the same period, science and technology in Japan have also been deeply affected by a national tragedy, the Great East Japan Earthquake of 2011. Other milestones will also go down in history: LDP's return to power in December 2012, heralding the launch of Abenomics, and the STAP cells controversy in 2014, which has shaken the scientific establishment and public trust in science.

Recent events and macro-trends have spawned fundamental challenges for the academic, government and industrial sectors. For the academic sector, university reform has clearly been a central challenge for some time. The ongoing reform is a multifaceted exercise involving the consolidation and merger of universities in the face of a declining young population, greater internationalization and the promotion of female researchers, enhanced collaboration with industry, development of a healthy research environment and better career prospects for young researchers. An overarching goal will be to improve the mediocre visibility of Japanese universities in the global landscape. Perhaps hardest of all, Japanese universities will be expected to carry out this array of reforms on a shrinking regular budget. This will demand a highly cost-effective use of public funding for universities; it will be important for the government to work in concert with the academic and industrial sectors to devise the most efficient use of the public purse in funding universities.

In April 2016, the *Fifth Basic Plan for Science and Technology* will become operational simultaneously with the start of the third six-year planning period for national universities. On this occasion, the ongoing reform of the university sector and its funding systems will need to move into higher gear, if it is to improve research productivity and diversify and internationalize university education. The academic community, in turn, will need to share its vision of the university of the future and strengthen internal governance mechanisms.

A major additional challenge for the academic community – and the government – will be to restore public confidence. Official statistics show that the triple catastrophe of 2011 has shaken the public's trust not only in nuclear technology but also in science and technology, in general. Moreover, just as public confidence was recovering, the STAP cells scandal broke. The academic community and the government should not content themselves with taking steps to prevent misconduct in research; they should also re-examine systemic aspects of the problem, such as the excessive concentration of R&D funds in a handful of institutions or laboratories, the vertiginous drop in regular funding and permanent research positions and evaluations of researchers based on short-term performance.

The academic community in Japan will also have to live up to the growing expectations of society. In addition to producing excellent research output, universities will be required to turn out high-quality graduates who can exercise leadership in today's speedy, globalized world fraught with uncertainty. Japanese universities will also be expected to collaborate keenly with industry to create social and economic benefits at the local, national, regional and global levels. In this respect, the role of public R&D institutes such as RIKEN and AIST will be particularly important because they can serve as arenas where academic, industrial and other stakeholders can readily interact. Also offering potential for innovation is the new Japan Agency for Medical Research and Development, established in April 2015 on the model of the US National Institutes of Health to realize Prime Minister Abe's vision of a vehicle to promote the Japanese medical industry.

The industrial sector in Japan has its own share of challenges. By 2014, Abenomics and other factors, including the recovery of foreign economies, had helped major Japanese firms recover from the global crisis but their financial health remains heavily dependent on relatively strong share prices. The effects of the past few years on investor confidence are still visible in the reluctance of Japanese firms to raise R&D spending or staff salaries and in their aversion to the necessary risk-taking to launch a new cycle of growth. Such a stance will not ensure the long-term health of the Japanese economy, since the positive effects of Abenomics cannot last forever.

One possible direction for Japanese industry would be for it to devise macrostrategies around a set of basic concepts suggested by the Japanese government in its *Comprehensive Strategy for STI*: 'smartization', 'systemization' and 'globalization'. It has become difficult for Japanese manufacturers to compete in the global market as far as the production of stand-alone commodities is concerned. However, Japanese industry can use its technological strength to satisfy global demand with system-oriented, network-based innovation supported by ICTs. In such fields as health care, urban development, mobility, energy, agriculture and disaster prevention, there are great opportunities worldwide for innovative firms to supply highly integrated, service-oriented systems. What Japanese industry needs is to combine its traditional strengths with a future-oriented vision. Such an approach could be applied to preparing for the 2020 Olympic/Paralympic Games in Tokyo; to that end, the Japanese government is now promoting STI via grants and other programmes in a broad range of fields, including environment, infrastructure, mobility, ICTs and robotics, using such keywords as 'sustainable,' 'safe and secure,' 'friendly to senior and challenged people,' 'hospitable' and 'exciting.'

Another possibility for Japan will be to promote creative industries in such areas as digital contents, online services, tourism and Japanese cuisine. The Ministry of Economy, Trade and Industry (METI) has been promoting the Cool Japan Initiative for several years now, which culminated in the establishment of the Cool Japan Fund Inc. by law in November 2013 to help Japan's creative industries spread their wings abroad. Such endeavours could be more tightly integrated into Japan's overall STI policy.

Almost a quarter of a century has passed since the Japanese economy entered the doldrums in the early 1990s. During this prolonged economic slump, each of the industrial, academic and governmental sectors in Japan has undergone reforms. Many electric, steel and pharmaceutical firms were merged and restructured, as were financial institutions; national universities and national research institutes were semi-privatized; and government ministries went through a comprehensive reorganization. These reforms have surely strengthened the foundation for R&D in Japan's industrial, academic and government sectors. What is needed now is for Japan to have confidence in its national innovation system. It needs to adopt forward-looking policies and arm itself with the courage to pursue the necessary reforms to adapt to the changing global landscape.

KEY TARGETS FOR JAPAN

- Raise the GERD/GDP ratio to 4% or more by 2020;
- Raise government expenditure on R&D to 1% of GDP or more by 2015;
- Position 100 institutions among the world's top 50 in specific fields for the citation of research papers by 2015;
- Raise the share of women occupying high-level posts in both the public and private sectors to 30% by 2020;
- Raise the proportion of women researchers by 2015 to 20% in science, 15% in engineering and 30% in agriculture, medicine, dental and pharmaceutical research;
- Attract 300 000 international students to Japan by 2020;
- Double the amount of FDI inflows (US$ 171 billion in 2013) by 2020.

REFERENCES

Govt of Japan (2014) *Comprehensive Strategy on STI*. Tokyo.

Govt of Japan (2011) *Fourth Basic Plan for Science and Technology*. Tokyo.

Japan Patent Office (2014) *Annual Report of Patent Administration 2014*. Tokyo.

MEXT (2014a) *The Status of University–Industry Collaboration in Universities in Financial Year 2013*. Ministry of Education, Culture, Sports, Science and Technology: Tokyo.

MEXT (2014b) *School Basic Survey*. Ministry of Education, Culture, Sports, Science and Technology: Tokyo.

MEXT (2014c) *Statistical Abstract of Education, Science and Culture*. Ministry of Education, Culture, Sports, Science and Technology: Tokyo.

MEXT (2014d) *White Paper on Science and Technology*. Ministry of Education, Culture, Sports, Science and Technology: Tokyo.

MEXT (2014e) *Survey on FTE Data for Researchers in Higher Education Institutions*. Ministry of Education, Culture, Sports, Science and Technology: Tokyo.

METI (2014f) *White Paper on Manufacturing*. Ministry of Economics, Trade and Industry: Tokyo.

NISTEP (2014) *Indicators of Science and Technology*. Ministry of Education, Culture, Sports, Science and Technology: Tokyo.

Science Council of Japan (2013) *Statement: Code of Conduct for Scientists. Revised Edition*. Tokyo.

Statistics Bureau (2014) *Survey of Research and Development*. Ministry of Internal Affairs and Communication: Tokyo.

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The government has decided to respond to [the] increasingly competitive [global] environment by raising its investment in research and development, strengthening the manufacturing sector and developing new creative industries.

Deok Soon Yim and **Jaewon Lee**

Songdo International Business District is a new smart city erected on 600 ha of reclaimed land on Incheon's waterfront, 65 km from Seoul. It is connected to Incheon International Airport by a 12 km-long bridge and forms part of the Incheon Free Economic Zone.

Photo © CJ Nattanai/Shutterstock.com

25 · Republic of Korea

Deok Soon Yim and Jaewon Lee

INTRODUCTION

Time for a new development model

The Republic of Korea[1] has become a benchmark for successful economic development. Between 1970 and 2013, GDP per capita grew from US$ 255 to US$ 25 976, driven by the strong manufacturing and industrial capabilities that turned it into one of Asia's economic 'tigers'. Among the many factors contributing to this success story is the country's commitment to technological progress and to developing an educated, skilled labour force. Today, the Republic of Korea is the only nation to have transformed itself from a major recipient of foreign aid into a major donor.

However, the government recognizes that this remarkable economic growth is no longer sustainable. Global competition with China and Japan is intense, exports are slipping and the global demand for green growth has altered the balance. In addition, a rapidly ageing population and declining birthrates threaten Korea's long-term economic development (Table 25.1). Middle-income households are straining to make ends meet in the face of stagnating wages and there are signs of evident social distress; the Organisation for Economic Co-operation and Development (OECD) reports that the Korean divorce rate has doubled in recent years and that its suicide rate is the highest of any OECD member. The time has come for an alternative development model.

The new priority: a creative economy

Against this backdrop, the government has been trying to set a new path by developing more competitive technologies. Under the Lee Myung-bak administration (2008–2013), the government embarked on a major campaign for 'low carbon technology and green growth,' as we saw in the *UNESCO Science Report 2010*. Lee's government targeted a 5% investment in research and development (R&D) as a percentage of GDP by 2012 and strengthened the ministry responsible for science and technology by transferring responsibility for the budget and co-ordination to the National Science and Technology Council (NSTC).

The current Park Geun-hye administration is emphasizing the 'creative economy,' in an effort to revitalize the manufacturing sector through the emergence of new creative industries.

TRENDS IN STI GOVERNANCE

Science to converge with culture, culture to fuse with industry

In her inaugural address in February 2013, President Park Geun-hye spoke of 'a new era of hope and happiness.' She identified five administrative goals for her government: a creative economy centred on jobs, tailored employment and welfare, creativity-oriented education and cultural enrichment, a safe and united society and strong security measures for sustainable peace on the Korean Peninsula. She offered a new vision for national development, defining it as 'the convergence of science and technology (S&T) with industry, the fusion of culture with industry and the blossoming of creativity in the very border areas that were once permeated by barriers.'

This new vision seeks to transform the country's economic model by deepening its reliance on science, technology and innovation (STI), which have served the country so well in the past. President Park's vision builds on that of her predecessor, who had managed to raise gross domestic expenditure on R&D (GERD) to 4.15% of GDP by 2013, the second-highest level of commitment in the world after Israel (Figure 25.1). This meteoric rise was made possible thanks largely to the strong progression in industrial R&D.

1. The present chapter covers only the Republic of Korea, so references to the abbreviation of 'Korea' designate solely the Republic of Korea.

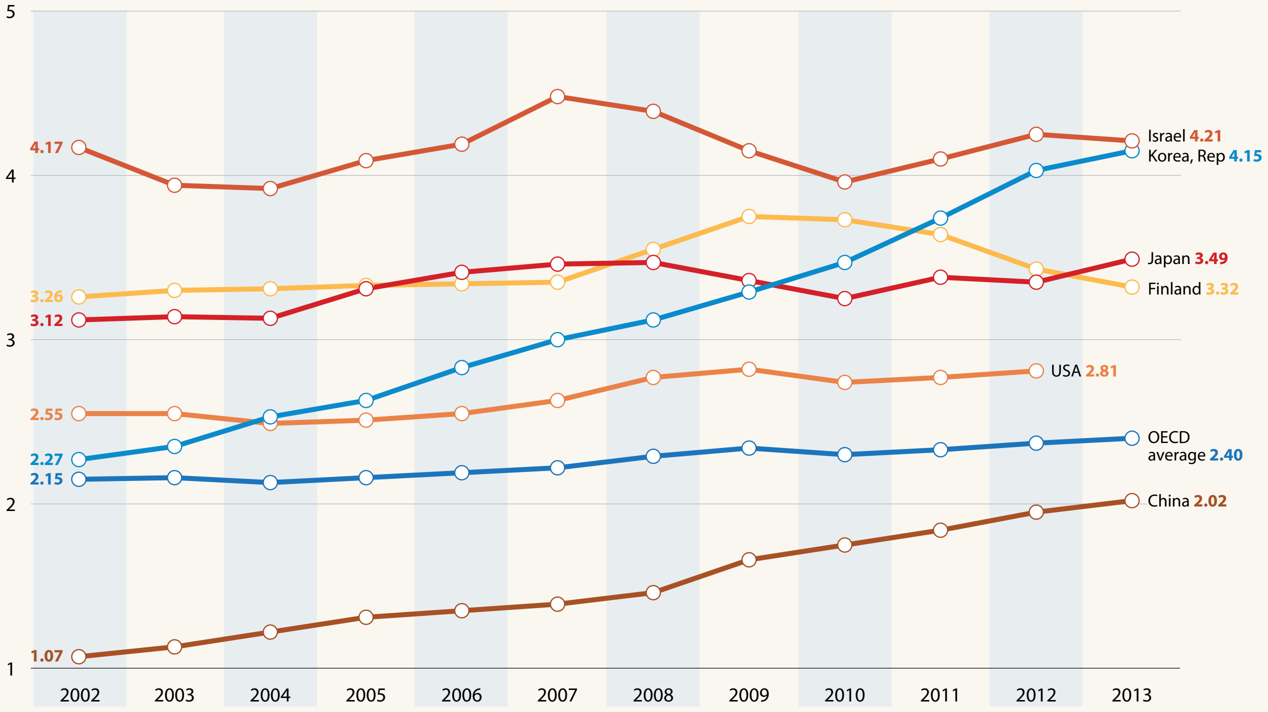
Table 25.1. **Socio-economic trends in the Republic of Korea, 2008–2013**

	2008	2009	2010	2011	2012	2013
Population (thousands)	48 948	49 182	49 410	49 779	50 004	50 219
Population growth rate (%)	0.62	0.62	0.60	0.57	0.55	0.53
GDP (current US$ millions)	1 002 216	901 934	1 094 499	1 202 463	1 222 807	1 304 553
GDP per capita (current US$)	20 474	18 338	22 151	24 155	24 453	25 976
GDP growth rate (%)	2.82	0.70	6.49	3.68	2.29	2.97
Life expectancy at birth (years)	79.8	80.3	80.6	81.0	81.4	–
Inflation, consumer prices (%)	4.67	2.76	2.96	4.00	2.20	1.31
Unemployment rate (% labour force)	3.20	3.60	3.70	3.40	3.20	3.1

Source: World Bank's World Development Indicators, accessed March 2015

Figure 25.1: **Progression in GERD/GDP ratio in Republic of Korea, 2002–2013 (%)**

Other countries and regions are given for comparison



Source: OECD (2015) *Main Science and Technology Indicators*

At the time of fixing this target in 2008, there had been some discordant opinions about the government's strong focus on industrial research and innovation. Some analysts underscored the need to lay greater emphasis on basic research and on upgrading the quality and performance of scientific research, in order to obtain greater global recognition. The previous Lee Myung-bak administration had taken various measures to address these issues, including its *Second Basic Plan for Science and Technology* over 2008–2013 and its Low Carbon, Green Growth policy.

High spending for low carbon, green growth

The *Second Basic Plan for Science and Technology over 2008–2013* came to be known as the 577 Initiative, in reference to the targets it proposed: the number 5 refers to 5% of GERD to GDP by 2012, the first 7 refers to the government's seven priority areas and the second 7 to the associated policy areas (MEST, 2011). The first target had not quite been achieved by 2012.

Between 2008 and 2011, the government invested KRW 23.72 trillion (US$ 28.1 billion) in the following seven priority areas:

- Advancement of key industries, such as the automobile, shipping and semi-conductor industries (KRW 2.06 trillion);
- Core technology for the development of new industries (KRW 3.47 trillion);
- Knowledge-based service industries (KRW 0.64 trillion);
- State-driven technology, such as space, defence and nuclear power (KRW 9.08 trillion);
- Issue-driven areas such as new diseases and nanodevices (KRW 3.53 trillion);
- Global issues such as renewable energy and climate change (KRW 3.78 trillion);
- Basic and convergent technology, such as intelligent robots and biochips (KRW 1.16 trillion).

The seven policy areas are:

- Nurturing talented students and researchers;
- Promotion of basic research;
- Support for SMEs to foster technological innovation;
- Stronger international co-operation in developing strategic technologies;
- Regional technological innovation;
- A stronger national base for S&T[2]; and
- Dissemination of a science culture.

2. This refers to increasing the number of national R&D facilities and developing a system of co-ordination to operate these facilities efficiently, which includes an online database on S&T, along with efforts to facilitate university–industry co-operation.

The 577 Initiative chalked up some impressive achievements (MEST, 2011):

- An increase in the number of publications recorded in international journals from 33 000 in 2009 to 40 000 in 2012, beyond the target of 35 000;
- An increase in the number of students on scholarships from 46 000 in 2007 to 110 000 in 2011;
- An increase in the number of researchers from 236 000 in 2008 to 289 000 by 2011, equivalent to 59 researchers per 10 000 population – this nevertheless supposes that the target of 100 researchers per 10 000 population will not be reached by 2012;
- A meteoric rise in the World Bank ranking of domestic environments for business creation, from 126th place in 2008 to 24th in 2012;
- An increase in GERD from 3.0% to 4.0% of GDP between 2007 and 2012 (Figure 25.1), driven largely by the business enterprise sector;
- A steep progression in the number of subscribers to the National Science and Technology Information Service, an internet-based platform for S&T statistics, from 17 000 in 2008 to 107 000 in 2010 – the government also introduced more transparent ways of evaluating S&T, including better indicators with more focus on quality control.

Within its Low Carbon, Green Growth policy (2008), the government established the Composite Measure for R&D in Green Technology in 2009. This measure proposes a series of development strategies and investment targets, including that of doubling government investment in green technology to KRW 2 trillion between 2008 and 2012. This target had been surpassed by 2011, when investment reached KRW 2.5 trillion. In all, the government invested KRW 9 trillion (*circa* US$ 10.5 billion) in green technology between 2009 and 2012.

The green growth policy has been institutionalized in the new *Five-Year Plans for Green Growth*, the first of which covered 2009–2013. In order to support both basic research and technological development in green technology, the government introduced its *Plan for National Carbon Dioxide Capture Sequestration* (CCS) in 2010. CCS is a technology for capturing carbon emissions on a large scale, such as those from power plants, and storing the carbon underground in disused mines and the like. The government plans to commercialize CCS technology by 2020. Total investment in green technology by the top 30 private companies amounted to KRW 22.4 trillion (US$ 26.2 billion) between 2011 and 2013.

The government also decided to host the Green Climate Fund in 2012 and supported the establishment of the Global Green Growth Institute[3] in 2010, which works with public and private partners in developing countries and emerging economies to put green growth at the heart of economic planning. The Green Climate Fund is based in the city of Incheon. The fund originated at the global climate talks in Copenhagen (Denmark) in 2009, where it was decided to create a fund endowed with US$ 100 billion per year by 2020 to help developing countries adapt to climate change. In November 2014, 30 countries meeting in Berlin (Germany) pledged[4] the first US$ 9.6 billion.

The government also launched the Green Technology Center Korea in 2013. This government-funded think tank co-ordinates and supports national R&D policies related to green technology, in collaboration with Korean ministries and agencies. The centre also serves as the Republic of Korea's gateway to international co-operation in the design and diffusion of green technology, with a focus on creating a new growth engine for developing countries. The Republic of Korea's partners in this endeavour are the United Nations Development Programme, United Nations Economic and Social Commission for Western Asia and the World Bank.

A blueprint for a creative economy

The *Third Basic Plan for Science and Technology, 2013–2017* came into effect in 2013, the year President Park Geun-hye took office. It serves as a blueprint for Korea's 18 ministries for the years to come. The major feature of this third plan is that it suggests, for the first time, that the government should allocate US$ 109 billion (KRW 92.4 trillion) to R&D over five years as seed money to foster the emergence of a creative economy (MSIP, 2014). This is expected to increase the contribution of R&D to economic growth from 35% to 40%. In addition, this third plan undertakes to raise gross national income per capita to US$ 30 000 and to create 640 000 jobs in science and engineering by 2017 (Table 25.2). These figures demonstrate how the current government plans to use science and technology to foster national growth, although some have questioned whether all of these targets can be reached by 2017.

The *Third Basic Plan* outlines five strategies for reaching these targets (NSTC, 2013) :

- Increase government investment in R&D, support private-sector R&D through tax relief and improve the planning of new research projects;

3. The Global Green Growth Institute was originally conceived by the Lee government as an NGO. It became an international body in 2012 after the signing of agreements with 18 governments. See: http://gggi.org

4. The biggest contributions to the Green Climate Fund were pledged by the USA (US $3 billion), Japan (US$ 1.5 billion), Germany, France and the UK (US$ 1 billion each). Some developing countries made pledges of a more modest nature, including Indonesia, Mexico and Mongolia.

Table 25.2: **The Republic of Korea's R&D targets to 2012 and 2017**

		Unit of measure	Situation as of 2007	Situation as of 2012	Target to 2012 of *Second Basic Plan*	Target to 2017 of *Third Basic Plan*
Financial investment	GERD	In KRW trillions	31.3	59.30^{+1}	–	–
		In current PPP$ billions	40.7	68.9^{+1}	–	–
		Percentage of GDP	3.00	4.15^{+1}	5.00	5.00
	Government-financed R&D expenditure	In KRW trillions	7.8	13.2	92.4 (total over 2012–2017)	
		Percentage of GDP	0.74	0.95^{+1}	1.0	–
	Share of basic research in government R&D budget	Percentage share	25.3	35.2	35.0	40.0
	Share of support for SMEs in government R&D budget	Percentage share	–	12.0^{-2}	–	18.0
	Government investment in green technology	In KRW trillions	1	2	2	–
	Government investment in quality of life	Percentage of government expenditure on R&D	–	15.0	–	20.0
Human capital investment	Researchers (FTE)	Total number	222 000	315 589	490 000^{-1}	–
		Per 10 000 population	47	64	100	–
	PhD-holders in science and engineering	Percentage of total population	–	0.4	–	0.6
	COSTII score	Ranking among 30 OECD countries	–	9th	–	7th
Output	Articles published in Science Citation Index	Total number	29 565	49 374	35 000	–
	Number of patents with international co-applications	Per 1 000 researchers	–	0.39^{-1}	–	0.50
	Technology competitiveness of SMEs	Percentage of total potential	–	74.8^{-1}	–	85.0
	Early-stage entrepreneurial activity	Percentage of enterprise's total activity	–	7.8	–	10.0
	Jobs in science and engineering	Total	–	6 050 000	–	6 690 000
	Gross national income per capita	US$	23 527	25 210	–	30 000
	Contribution of R&D to economic growth	Percentage of GDP	30.4^{-1*}	35.4**	40.0***	40.0****
	Industrial value added per capita	US dollars	–	19 000	–	25 000
	Value of technology exports	US dollars millions	2 178	4 032	–	8 000
	Technology trading	Ratio of technology revenue to expenditure	0.43	0.48	0.70	–

-n/+n = n years before or after reference year.

* average contribution over 1990–2004
** average contribution over 1981–2010
*** average contribution over 2000–2012
**** average contribution over 2013–2017

Note: The Composite Science and Technology Innovation Index (COSTII) was developed by the Korean National Science and Technology Council in 2005. It compares the innovation capacity of 30 OECD countries.

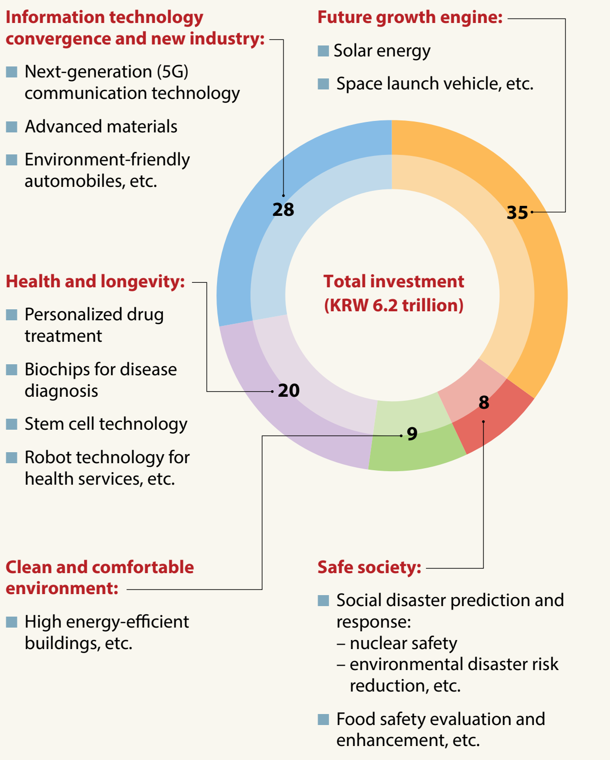
Source: MEST (2008); MSIP (2014b); UNESCO Institute for Statistics; MSIP (2013c)

- Identify five strategic areas for national technological development (Figure 25.2);
- Nurture creative talent by, for example, providing more funding for basic research and inviting 300 eminent foreign scientists to visit and work with national laboratories, etc.;
- Increase support for small and medium-sized enterprises (SMEs) to help them market their research output and technology;
- Create more jobs by enabling 'ecosystems' to support start-ups in science and technology, through funding, consultation services, etc.

Within the five strategic areas mentioned above, a total of 120 strategic technologies have been designated by the government, 30 of which are considered investment priorities over the five years to 2017, by which time the government expects some of these to be technologically feasible. As of mid-2015, the government had not yet announced budgetary targets to 2017. The Ministry of Science, ICTs and Future Planning (MSIP) is in the process of designing a strategic roadmap which will include an implementation plan.

Figure 25.2: **The Republic of Korea's strategic technologies for 2013–2017**

Budget share (%)



Source: NSTC (2013)

A reshuffle of the country's administrative cards

Several government bodies were restructured between 2009 and 2013. In particular, the Park Geun-hye administration established a new Ministry of Science, ICTs and Future Planning (MSIP). MSIP took over responsibility for S&T from the Ministry of Education, Science and Technology (MEST) and recovered some parts of broadcasting and communications from the Korea Communications Commission and some tasks from the Ministry of Knowledge Economy, which was renamed the Ministry of Trade, Industry and Energy.

The National Science and Technology Council (NSTC) was given greater authority in 2011 to meet the demand for greater convergence between science and technology. Its co-ordination function has been reinforced to enable it to prepare the *Basic Plans for Science and Technology* and the *Basic Plans for the Promotion of Regional Science and Technology*, among other documents. The council has also assumed deliberative and legislative power over major plans related to S&T that are suggested by each ministry. It has also recovered responsibility for evaluating national R&D programmes and for fixing the national R&D budget. Moreover, in an effort to streamline co-operation between the government and the private sector, the NSTC is now jointly chaired by the Prime Minister and a person designated by the President from the private sector (NSTC, 2012).

TRENDS IN R&D

The 5% target within reach for 2017

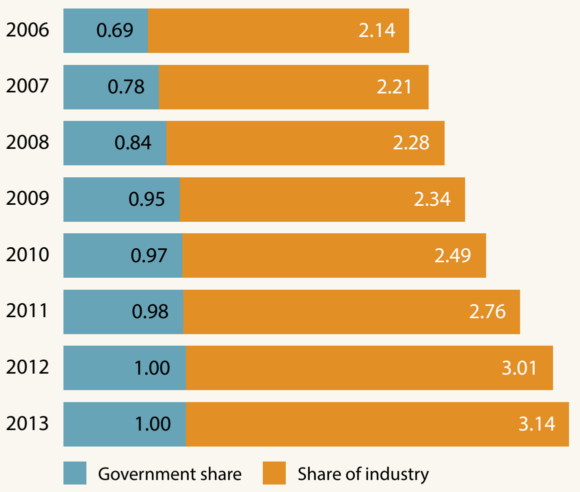
R&D financed by the Government and other national sources has risen almost continually since 1993. By 2008, it was rising by 13.3%[5] per year. The global financial crisis slowed the growth rate somewhat to 11.4% in 2010 and it slipped farther in 2014 to 5.3%. This decline in government funding has been offset by the industrial sector, which funds three-quarters of GERD and managed to increase its own investment in R&D between 2009 and 2013 by an average of 12.4% each year (Figures 25.3–25.5). As a consequence, the GERD/GDP ratio pursued its progression, albeit at a slower pace than that anticipated by the *Second Basic Plan for Science and Technology*. The Republic of Korea may have missed its target of devoting 5% of GDP to GERD by 2012 but the government is determined to see that this target is reached by 2017 (Kim, 2014).

More resources for basic research

Government investment in basic research has changed focus since 2008 by placing greater emphasis on quality. This has also entailed improving the quantity of allocated

5. If other national sources are excluded, government-funded R&D expenditure grew by 12.9% in 2009 and 2010 but only by 2.4% in 2013, according to the UNESCO Institute for Statistics.

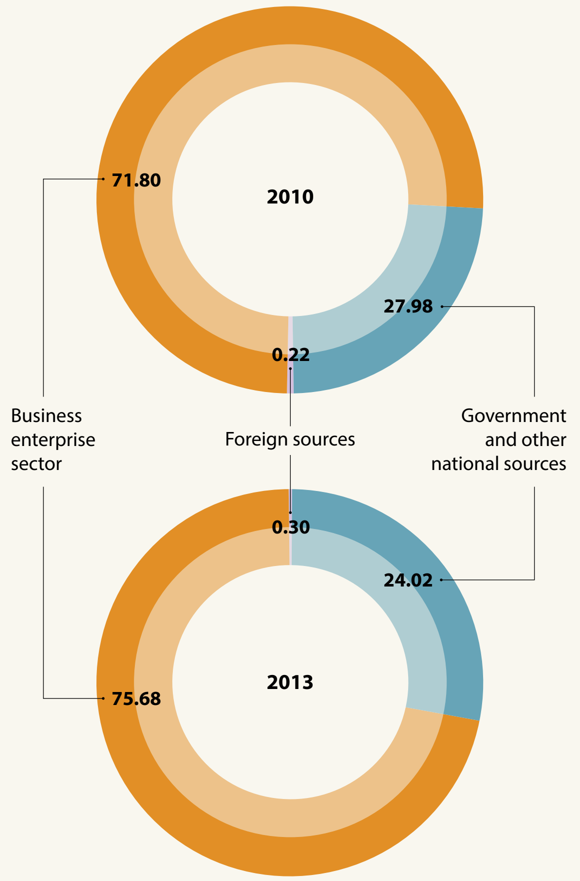
Figure 25.3: **GERD in the Republic of Korea by source of funds and as a share of GDP, 2006–2013** (%)



Note: The government share refers to R&D financed by the government, the higher education sector and other national sources but the contribution of all but the government share is negligible.

Source: MSIP (2014b)

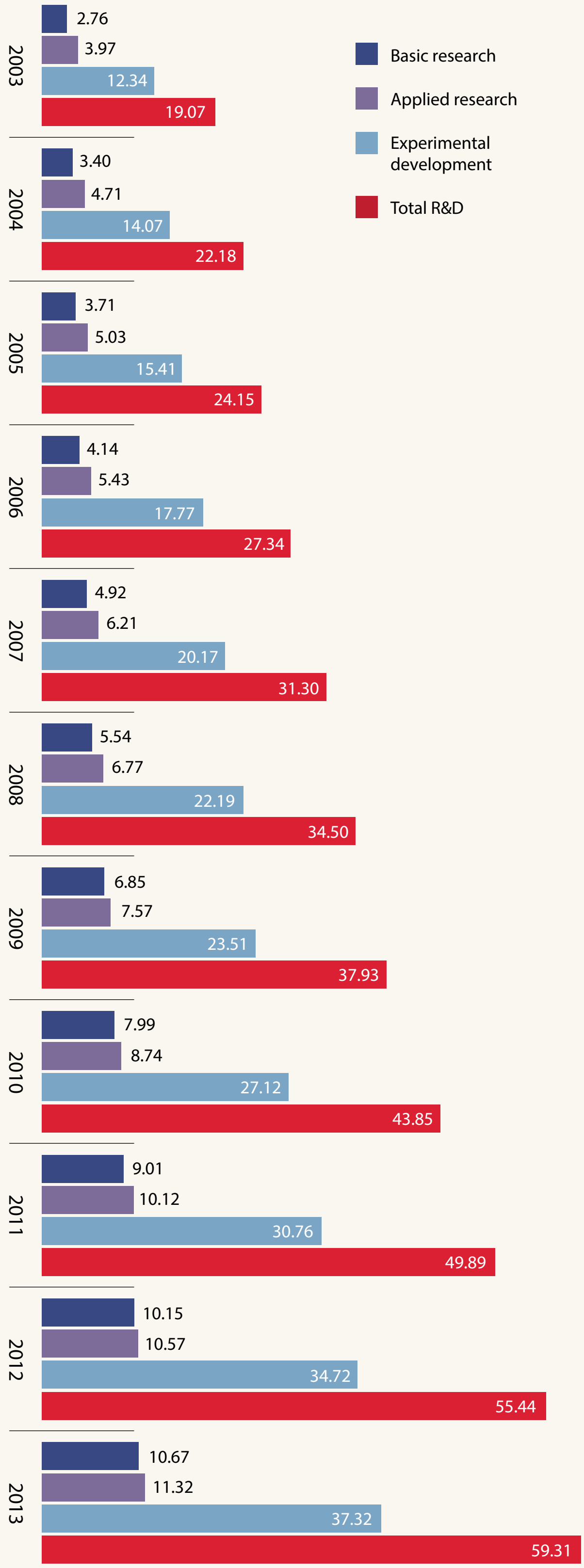
Figure 25.4: **GERD in the Republic of Korea by source of funds, 2010 and 2013** (%)



Source: MSIP (2014b)

Figure 25.5: **GERD in the Republic of Korea by type of research, 2003–2013**

In KRW trillions



Source: MSIP (2014b)

funds. The share of GERD devoted to basic research rose from 15.2% in 2006 to 18.1% in 2009, a share maintained ever since. This was largely thanks to the *Second Basic Research Promotion Plan*, which raised the basic research budget from 25.6% of government spending on R&D (2008) to 35.2% (2012). In parallel, funding allocated to individual basic scientists tripled over the same period from KRW 264 billion to KRW 800 billion (*circa* US$ 936 million) [MSIP, 2014a].

The current government is pursuing this policy. This can be seen in the budget allocated to the International Science Business Belt, currently under construction in the city of Daejeon. This ambitious project was enshrined in the *Basic Plan for an International Science Business Belt,* adopted by the Lee government in 2011. The aim is to correct the impression that the Republic of Korea made the transition from a poor agricultural country to an industrial giant through imitation alone, without developing an endogenous capacity in basic sciences. A National Institute for Basic Science opened on the site in 2011 and a heavy ion accelerator is currently under construction to support basic research and provide linkages to the business world (Box 25.1). Between 2013 and 2014, the Park government doubled the 'business belt's' budget to KRW 210 billion (*circa* US$ 246 million) [Kim, 2014].

The heavy ion accelerator should enable Korean scientists to improve their productivity in physics, which has evolved little since 2008, contrary to biological sciences (Figure 25.6).

Efforts to develop regional autonomy in R&D

The third *National Plan for the Regional Development of Science and Technology 2008–2012* was awarded a much greater share of investment than its two predecessors. The R&D budget for the regions was multiplied by 15 between 2008 and 2013, soaring from KRW 4 689 billion (*circa* US$ 5.9 billion) to KRW 76 194 billion (*circa* US$ 89.2 billion). This budget excludes Seoul and the city of Daejeon, where Daedeok Innopolis is located, the heart of the country's high-tech research community. Much of the funding went on building R&D infrastructure (MSIP, 2013a). This rise should be qualified, however; the share of regional R&D investment in relation to GERD actually remained constant at about 45% of the total over this period. Despite the massive injection of funds, a government evaluation of the third plan's implementation concluded that regional governments remained excessively reliant on central government funding for R&D and that regional R&D remained highly inefficient (MSIP, 2014a). Consequently, the fourth *National Plan for the Regional Development of Science and Technology 2013–2017* has fixed the objective of strengthening regional autonomy and responsibility for R&D. It is reviewing the feasibility of decentralizing inclusive R&D budgets to regional authorities and of improving R&D planning and management capabilities at regional level (MSIP, 2014a).

Industrial production and technology still dominate R&D

Despite the new focus on basic research, 'industrial production and technology' still represented two-thirds of GERD in 2013 (Figure 25.7). Of note is that R&D investment in health and environment rose by more than 40% between 2009 and 2012.

The number of private R&D centres increased by 50% between 2010 and 2012, from 20 863 to 30 589. Since 2004, more than 90% of corporate research institutes have been operated by SMEs and venture companies, although large

Box 25.1: **The Republic of Korea's Silicon Valley**

Moving away from its earlier focus on catch-up technology, the Republic of Korea has invested in a dedicated world-class science and business cluster in and around the city of Daejeon, less than an hour's journey from Seoul in a high-speed train. The International Science Business Belt dates from 2011. It is the country's biggest research complex, home to 18 universities, several science parks and dozens of research centres, both private and public.

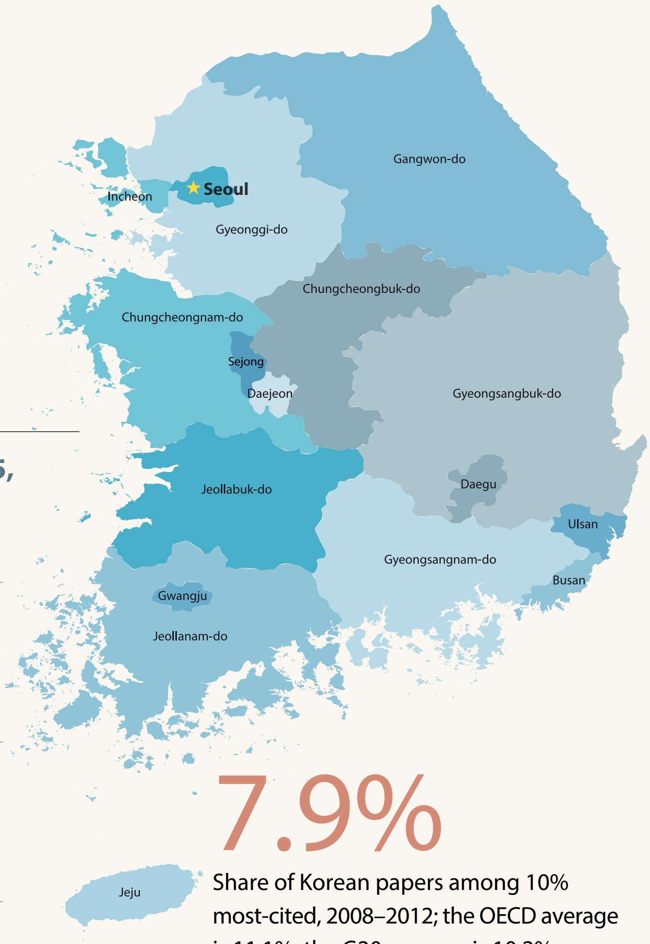
The jewel in the crown will be a heavy ion accelerator, due for completion by 2021. It will form part of the multi-functional research facility now called RAON. Here, researchers will be able to carry out groundbreaking research in basic science and look forward to discovering rare isotopes. RAON will be hosted by the Institute for Basic Science, which is itself under construction. It should open its doors in 2016. The institute plans to attract world-renowned scientists and to cultivate an environment that maximizes the researcher's autonomy; it intends to make its mark among the top 10 world-class research institutes in basic science with a measurable impact on society by 2030.

In order to foster synergies and convergence between basic science and business, high-tech companies and leading enterprises are being invited to group themselves around hubs such as the Korea Basic Science Institute.

The ultimate aim is to build a global city combining science, education, culture and art, where creativity, research and innovation can flourish, as they do in Silicon Valley in the USA or in the cities of Boston (USA), Cambridge (UK) or Munich (Germany).

Source: NTSC (2013), www.isbb.or.kr/index_en.jsp, http://ibs.re.k

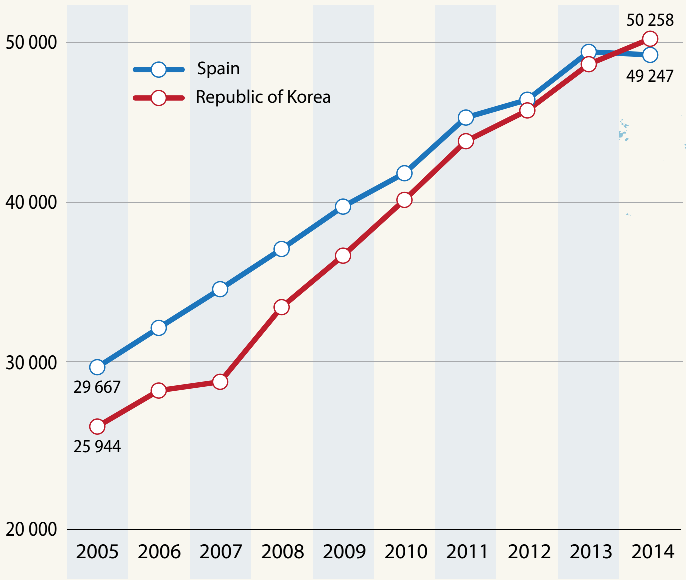
Figure 25.6: **Scientific publication trends in the Republic of Korea, 2005–2014**



0.89

Average citation rate for Korean publications, 2008–2012; the OECD average is 1.08; the G20 average is 1.02

Korean publications have nearly doubled since 2005, overtaking those of similarly populated Spain



7.9%

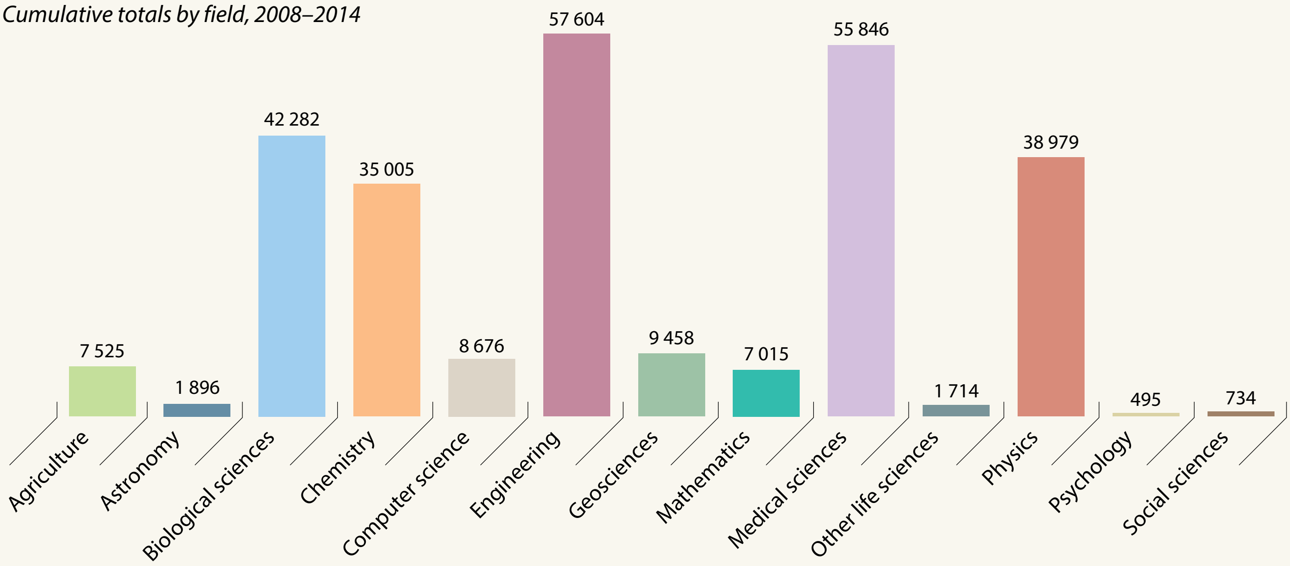
Share of Korean papers among 10% most-cited, 2008–2012; the OECD average is 11.1%; the G20 average is 10.2%

27.6%

Share of Korean papers with foreign co-authors, 2008–2014; the OECD average is 29.4%; the G20 average is 24.6%.

Korean scientists publish most in engineering, physics, chemistry and life sciences

Cumulative totals by field, 2008–2014



The USA remains the Republic of Korea's main partner, followed by Japan and China

Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Rep. of Korea	USA (42 004)	Japan (12 108)	China (11 993)	India (6 477)	Germany (6 341)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

conglomerates accounted for 71 % of all private investment in R&D in 2009 and 74% in 2012. This shows that just a handful of major companies are the principal investors in Korean R&D, even though SMEs and venture companies play a key role by establishing and operating R&D centres.

Strong growth in domestic and international patents

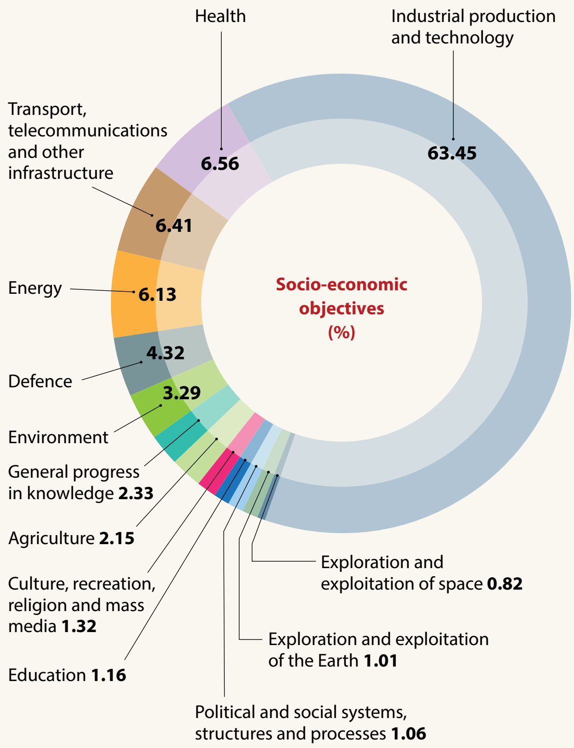
The number of domestic patents registered more than doubled between 2009 and 2013 from 56 732 to 127 330 (KIPO, 2013). This is quite a feat, especially coming as it does in the wake of the global financial crisis. In 2013, Koreans took third place (14 548) for the number of patents registered in the USA, behind Japan (51 919) and Germany (15 498).

The country also recorded a rise within triadic patent families – an aggregate of registrations with patent offices in Europe, Japan and the USA – even though the ratio per billion KRW of research budget slipped (Figure 25.8). This didn't prevent Korean inventors from ranking fourth in 2012.

Technology trade has doubled

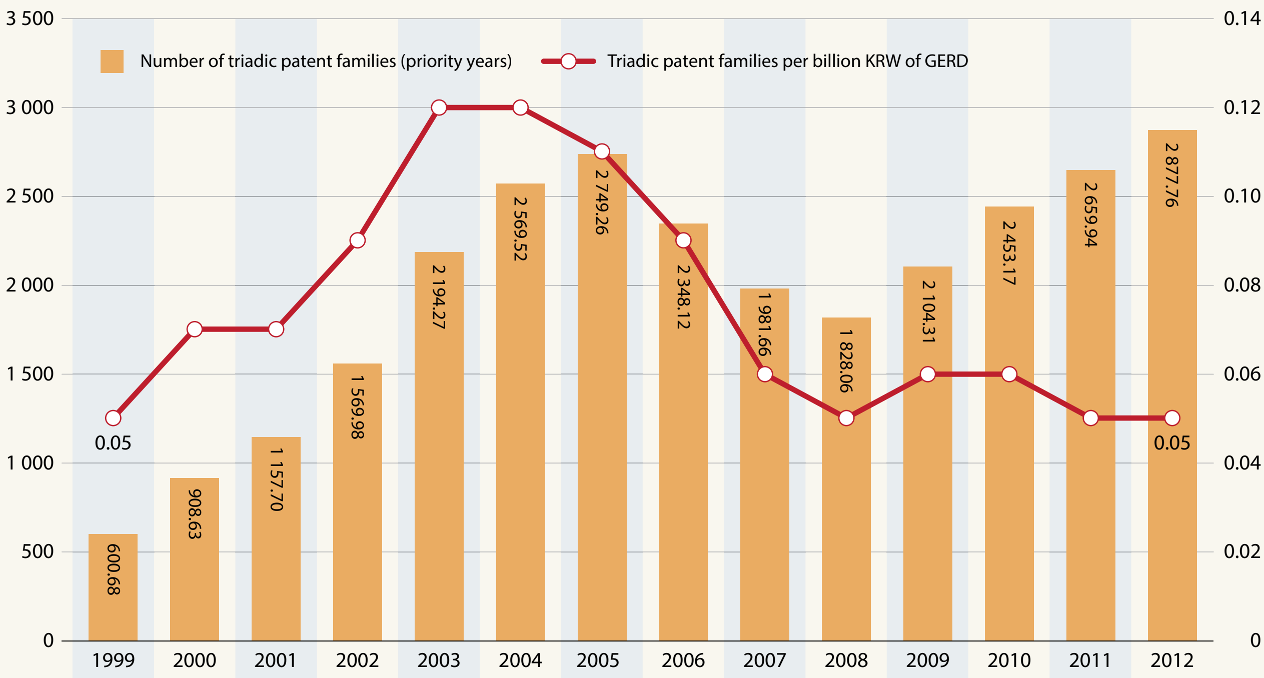
The volume of technology trade doubled between 2008 and 2012 from US$ 8.2 billion to US$ 16.4 billion. The trade balance, which can be calculated as a ratio of technology exports to technology imports, improved from 0.45 in 2008 to 0.48 in 2012 (MSIP, 2013b). Although this increasing volume of technology trade implies that the country is actively engaging in global innovation, it continues to record a large deficit in the global technology marketplace that it is striving to remedy.

Figure 25.7: **GERD in the Republic of Korea by socio-economic objective, 2013** (%)



Source: MSIP (2014b)

Figure 25.8: **Triadic patent family registrations in the Republic of Korea, 1999–2012**



Source: MSIP (2014b)

The volume of Korean high-tech exports (US$ 143 billion) is comparable to that of Singapore (US$ 141 billion) and higher than that of Japan (US$ 110 billion). Six out of ten high-tech exports fall into the category of electronics and telecommunications; exports in this sector even increased from US$ 66.8 billion in 2008 to US$ 87.6 by 2013.

Most countries experienced a dip in high-tech exports in 2009 after the global financial crisis hit but, whereas the Republic of Korea and Singapore rapidly recovered, the volume of high-tech exports stagnated in Japan and has not yet recovered in the USA, where high-tech exports earned US$ 237 billion in 2008 but just US$ 164 billion five years later.

Great strides in technological competitiveness

In 2014, the Republic of Korea ranked 6th for scientific competitiveness and 8th for technological competitiveness, according to the Institute of Management Development, based in Switzerland. The rankings for both science and technology have improved hugely since the turn of the century but it is in technological competitiveness that Korea has made the biggest strides in the past five years. The country is particularly efficient in communication technologies. For example, it ranked 14th in 2014 for mobile telecommunication costs per minute, compared with 33rd a year earlier. Other indicators surveyed remained sluggish, however. For example, in terms of technological co-operation among corporations, Korea it ranked 39th, whereas its rank on cybersecurity issues was downgraded from 38th to 58th over the same period. This correlates with the drop in scientific productivity in computer sciences observed in recent years.

TRENDS IN HUMAN RESOURCES

Korea now ranks sixth for the number of researchers

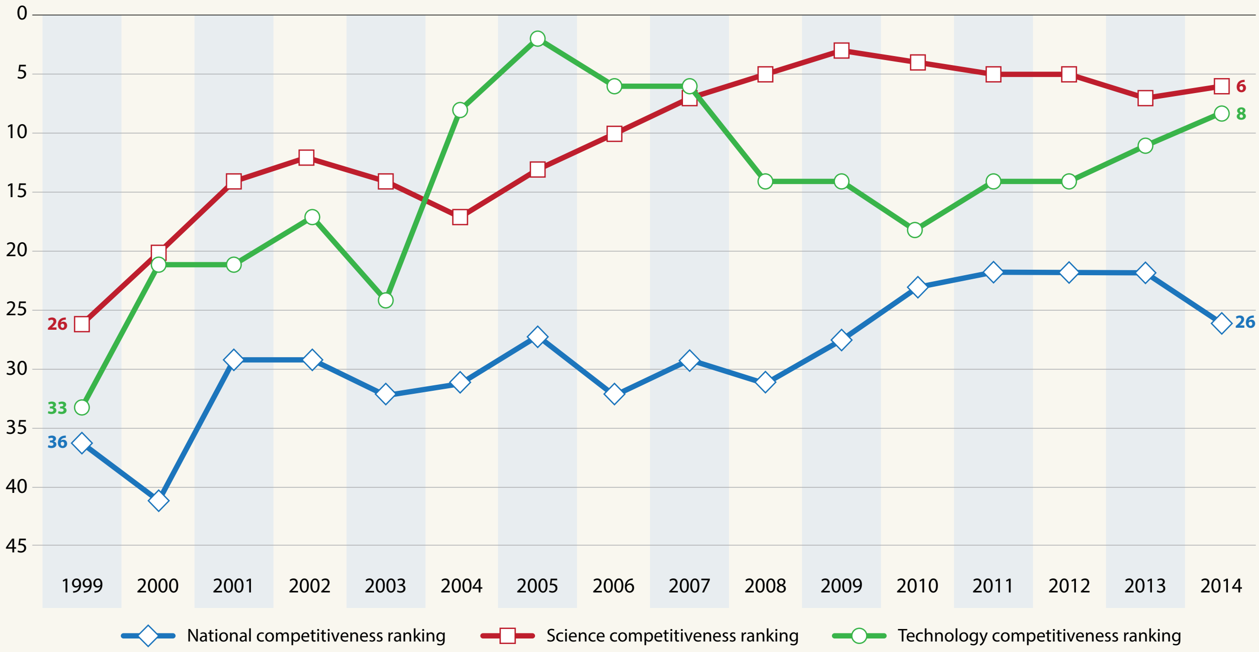
The number of full-time equivalent (FTE) researchers grew steeply between 2008 and 2013 from 236 137 to 321 842 (Figure 25.10). As a result, the Republic of Korea now ranks sixth for this indicator after China, the USA, Japan, the Russian Federation and Germany. More importantly, the Republic of Korea has more researchers per million population than any of these countries: 6 533 in 2013. In terms of researcher density, it is surpassed only by Israel and some Scandinavian countries. Moreover, thanks to the steady rise in the country's GERD/GDP ratio, the investment available to each researcher has managed to keep pace with the burgeoning numbers of personnel, even climbing slightly from PPP$ 186 000 to PPP$ 214 000 between 2008 and 2013 (Figure 25.10).

Women remain a minority in Korean science

In 2008, only one in six researchers (15.6%) was a woman. The situation has improved somewhat since (18.2% in 2013) but the Republic of Korea still lags far behind the beacons for this indicator, Central Asia and Latin America, where about 45% of researchers are women, even if it performs better than Japan (14.6% in 2013). When it comes to remuneration, there is a yawning gap between men and women researchers in the Republic of Korea (39%), the widest of any OECD country. Japan has the next-biggest gap in remuneration (29%).

The government is cognizant of the problem. In 2011, it introduced a *Second Basic Plan for Women Scientists and*

Figure 25.9: **Changes in Republic of Korea's competitiveness ranking in science and technology, 1999–2014**

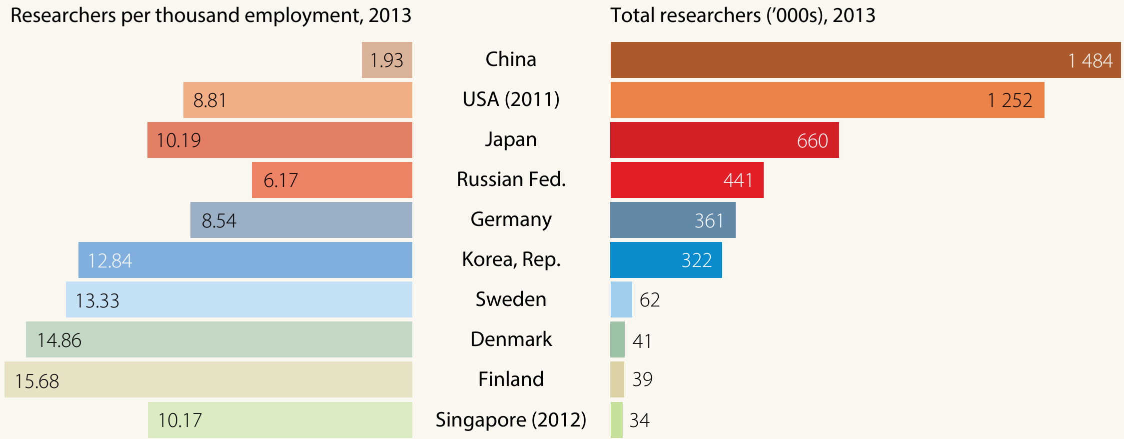


Source: IMD (2014) *World Competitiveness Yearbook*. Institute of Management Development: Lausanne (Switzerland)

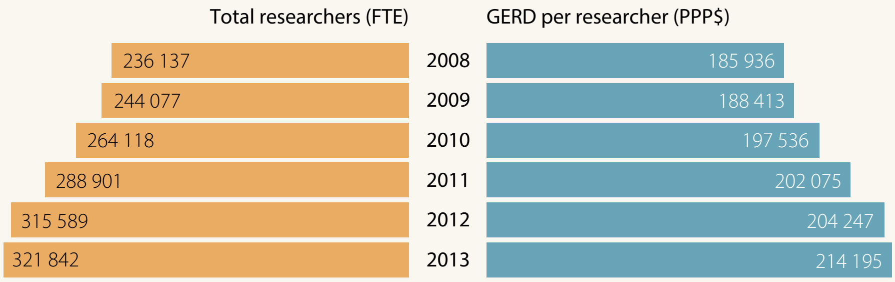
Figure 25.10: **Trends among Korean researchers (FTE), 2008–2013**

The Republic of Korea has one of the world's greatest researcher intensities

Other countries are given for comparison



The budget per researcher has risen since 2008



Source: OECD (2015) *Main Science and Technology Indicators*

Engineers (2009–2013), which outlines measures for fostering career development and making the working environment more women-friendly. In 2011, centres for women in science and technology lodged within several universities merged to form the Centre for Women in Science, Engineering and Technology (WISET). WISET develops policies to mainstream women in science, engineering and technology. The centre held a Gendered Innovation Forum in March 2014 to bring Korean experts together with science attachés from embassies in Seoul. The centre is also hosting the next Gender Summit in Seoul in late 2015. The first gender summits have been held in Europe and the USA since 2011. This will be the first such event in Asia.

Measures to nurture creative talents

The Korean government has come to realize that developing national capabilities for innovation will require nurturing creativity among the young (MSIP, 2013b). To this end, it has outlined several strategies for the 'renaissance of the natural sciences and engineering'. Ministries have jointly introduced 'measures to nurture creative talents', in order to attenuate the focus on academic backgrounds and promote a new culture whereby people encourage and respect the creativity of individuals. One example of these measures is the Da Vinci Project being experimented in selected primary and secondary schools to develop a new type of class which encourages students to exercise their imagination and which revitalizes hands-on research and experience-based education.

The government is also promoting the Open Academy Project with the Korea Advanced Institute of Science and Technology and other universities to establish an online platform where students can study and enter into discussion with professors. There are plans to make online courses accessible to anyone with an interest in studying and to link these courses to an academic credit banking system to ensure that the credits obtained by students enrolled in these online courses are recognized.

The *Second Basic Plan for Nurturing Human Resources in Science and Engineering* (2011–2015) aims to foster human resources in science and technology by focusing on the development of creativity, the scope of which is to be expanded to include elementary and secondary education. The government is promoting education for science, technology, engineering, arts and mathematics (STEAM) to promote the convergence of these fields and help students grasp economic and social challenges in the future. Brain Korea 21 plus has been implemented within the scope of the plan (Box 25.2). The government has also expanded its financial support to young researchers: the number of projects qualifying for government support rose from 178 (KRW 10.8 billion) in 2013 to 570 (KRW 28.7 billion) in 2014.

Based on the *Medium-and Long-term Supply and Demand Forecast for Human Resources in Science and Technology* (2013–2022), the country will face an excess of 197 000 graduates and 36 000 postgraduates with a master's degree by 2022, whereas there will be shortage of 12 000 PhD-holders.

As industry needs a greater number of employees with training in science and technology than in the past, policy measures will need to correct this misalignment. For example, the government plans to conduct a foresight exercise with a focus on human resource needs in emerging technologies to make up for the projected shortfall in these fields.

A creative economy town

The Creative Economy Town[6] is one example of a series of offline and online platforms set up by the Park government to allow individuals to share and commercialize their ideas. Professionals from relevant fields act as mentors, providing legal advice on intellectual property rights and other issues and connecting budding innovators with companies which have the potential to market their ideas.

A second example is the Innovation Center for the Creative Economy. This government centre is located in Daejeon and Daegu and serves as a business incubator.

These initiatives are not without controversy, however, as some feel that the government is intervening too much. The main question hinges on whether or not entrepreneurship can be better fostered with government support or by leaving entrepreneurs to fend for themselves in the marketplace.

A survey conducted by the Korea Federation of Small and Medium-Sized Enterprises in 2014 revealed that the federation's members judged the level of entrepreneurship in the Republic of Korea to be quite low.[7] It is still too early at this point to analyse whether or not the government's efforts have succeeded in fostering innovation.

A more systemic approach to co-operation

Korean scientists have been participating in international projects and exchanges for years. Some 118 scientists collaborated with the European Organization for Nuclear Research (CERN) in 2013, for instance. The Republic of Korea is also a partner in the project which is currently building an International Thermonuclear Experimental Reactor in France and invested around KRW 278 billion in this project from 2012 to 2014. The government also contributed KRW 20 million (*circa* US$ 23 000) to support the participation of more than 40 individual Korean researchers in the European Union's Seventh Framework Programme for Research and Technological Development from 2007–2013 (MSIP, 2012).

6. https://www.creativekorea.or.kr

7. http://economy.hankooki.com/lpage/industry/201410/e20141028102131120170.htm

Box 25.2: **Brain Korea 21 Plus: the sequel**

The *UNESCO Science Report 2010* followed the fortunes of the Brain Korea project, which had been renewed in 2006 for another six years. Within this project, universities and graduate schools wishing to qualify for government funding were obliged to organize themselves into research consortia. The aim was to encourage world-class research.

This approach seems to have worked, for the performance and output of both participating graduates and faculties effectively improved. For example, the number of articles produced by university staff and graduates increased between 2006 and 2013 from 9 486 to 16 428. Importantly, the impact factor per article also progressed: from 2.08 in 2006 to 2.97 in 2012 (NSTC, 2013).

Encouraged by this success, the project was extended for another six years in 2013, under the name of Brain Korea 21 Plus. In its first year, the project received an allocation of KRW 252 billion (*circa* US$ 295 million).

Whereas the initial project focused on increasing the quantity of R&D performed, Brain Korea 21 Plus is focusing on improving the quality of both teaching and research at local universities, along with their ability to manage projects. By 2019, the project hopes to have enrolled a great deal more students in accredited master's and PhD programmes than in the past, in order to nurture some of the talent that will be needed to develop a more creative economy.

Source: https://bkplus.nrf.re.kr

The government is also encouraging Korean collaboration with world-class laboratories through a home-grown scheme, the Global Research Laboratory Programme, which was launched in 2006. Each year, the Ministry of Science, ICTs and Future Planning and the National Research Foundation invite Korean research institutions to answer their call for project proposals. These proposals may concern basic sciences or technological fields, as long as the research topic necessitates collaboration with laboratories abroad. Successful joint projects may be awarded annual funding of KRW 500 million (*circa* US$ 585 000) for up to six years. The number of Global Research Laboratory projects has increased from 7 in 2006 to 48 in 2013 (MSIP, 2014a).

The current government is particularly keen to see the private sector develop core technologies by investing in foreign companies. The *National Plan for International Co-operation in Science, Technology and ICTs* (2014) sets out to do just that. A key element of the plan is the establishment of the Korea Innovation Centre, which will play a supporting role for Korean researchers and entrepreneurs eager to invest abroad while attempting to woo foreign investors to Korean shores (Box 25.3).

Some forms of international assistance also incorporate science and technology, such as the Techno Peace Corps programme, which funds postdoctoral students. Another example is the project being implemented by the government in Viet Nam to establish the Viet Nam–Korea Institute of Science and Technology. The government also plans to establish 'centres for appropriate science and technology' in developing countries, in order to provide post-management of projects, including consultancies and education; for example, the government has established an innovative Water Centre (iWc) in Cambodia to boost Cambodian R&D oriented towards providing a clean water supply and serve as a base for the Republic of Korea's international assistance in science and technology. The government's overall budget for this type of international assistance is expected to increase from KRW 8.2 billion in 2009 to KRW 28.1 billion (*circa* US$ 32.9 million) in 2015 (Kim, 2011).

CONCLUSION

A new orientation towards entrepreneurship and creativity

The Republic of Korea has come through the global financial crisis since 2008 remarkably unscathed. However, this should not mask the fact that the country has outgrown its catch-up model. China and Japan are competing with Korean technology in global markets and exports are slipping as global demand evolves towards green growth.

The government has decided to respond to this increasingly competitive global market by raising its investment in R&D, strengthening the manufacturing sector and developing new creative industries. The country's investment in R&D has already risen quite substantially but there is now some doubt as to whether this has produced the desired result. It may be that investment in R&D has reached a point where marginal growth in the performance of R&D is close to zero. The Republic of Korea thus now needs to optimize the management of its national innovation system to take full advantage of this rising investment.

Without a corresponding restructuring of industry and its accompanying innovation system, the injection of R&D funding

Box 25.3: The Korea Innovation Centre

Established in May 2014 as part of the new 'creative economy,' the Korea Innovation Centre promotes Korean exports and the internationalization of national researchers.

It also incites venture companies and SMEs to enter the world market. In order to encourage networking and common platforms for co-operation, it is opening up offices in the European Union (Brussels), the USA (Silicon Valley and Washington, DC), China and the Russian Federation, as well as at home.

The Korea Innovation Centre is operated jointly by the National Research Foundation, which provides the secretariat, and the National Information Technology Industry Promotion Agency. Its mission is aligned with the five strategies designated under the 2014 *National Plan for International Co-operation in Science, Technology and ICTs:*

- Establish systemic linkages to support international co-operation and overseas business;
- Enhance support for SMEs to launch overseas ventures;
- Strengthen innovation capacities by developing world-class human resources in STI;
- Strengthen international co-operation and partnerships in science, technology and ICTs;
- Create more efficient management systems to respond to international demand.

Source: www.msip.go.kr

may not be able to produce better output. As posited by the theory of innovation systems, the total productivity of a national innovation system is a key factor for change but it is also quite difficult to transform the national innovation system, as it tends to be an 'ecosystem' that is most concerned with linking the various actors through relationships and processes.

The country is now striving to become more entrepreneurial and creative, a process that will entail changing the very structure of the economy. Up until now, it has relied on large conglomerates such as Hyundai (vehicles) and Samsung and LG (electronics) to drive growth and export earnings. In 2012, these conglomerates still represented three-quarters of private investment in R&D – an even higher share than three years previously (KISTEP, 2013). The challenge will be for the country to produce its own high-tech start-ups and to foster a creative culture in SMEs. Another challenge will be to turn the regions into hubs for creative industries by providing the right financial infrastructure and management to improve their autonomy.

KEY TARGETS FOR THE REPUBLIC OF KOREA

- Raise GERD from 4.03% to 5.0% of GDP between 2012 and 2017;
- Ensure that SMEs achieve 85% of their potential technological competitiveness by 2017, compared to 75% in 2011;
- Raise support for SMEs from 12% of the government R&D budget in 2012 to 18% by 2017;
- Raise the share of basic research in the government budget from 32% in 2012 to 40% by 2017;
- Raise the share of government investment in improving the quality of life through R&D from 15% in 2012 to 20% in 2017;
- Increase the number of jobs in S&T from 6.05 million to 6.69 million by 2017;
- Increase the share of early-stage entrepreneurial activity in enterprises from 7.8% in 2012 to 10% in 2017;
- Increase the number of PhD-holders from 0.4% to 0.6% of the population between 2012 and 2017;
- Raise industrial added value per capita from US$ 19 000 in 2012 to US$ 25 000 by 2017;
- Commercialize the technology for carbon dioxide capture sequestration by 2020;
- Double the value of technology exports from US$ 4 032 million to US$ 8 000 million between 2012 and 2017.

In sum, the government's agenda for a creative economy reflects a growing consensus that the country's future growth and prosperity will depend on its ability to become a global leader in developing and commercializing innovative new products, services and business models.

REFERENCES

IMD (2014) *World Competitiveness Yearbook*. Institute of Management Development: Lausanne (Switzerland).

Kim, I. J. (2014) Government Research and Development Budget Analysis in the 2014 Financial Year. Korea Institute of Science and Technology Evaluation and Planning: Seoul.

Kim, Ki Kook (2011) *Vision and Assignments for Korean Science and Technology Overseas Development Assistance for the Post Jasmine era*. Science and Technology Policy Institute: Seoul.

KIPO (2013) *Intellectual Property Statistics for 2013*. Korean Intellectual Property Office: Daejeon.

KISTEP (2013) *Status of Private Companies R&D Activities in Korea*. Korea Institute of Science and Technology Evaluation and Planning: Seoul.

MEST (2011) *Science and Technology Yearbook 2010*. Ministry of Education, Science and Technology: Seoul.

MEST (2008) *Second Basic Plan for Science and Technology, 2008–2013*. Ministry of Education, Science and Technology: Seoul.

MSIP (2013a) Fourth National Plan for the Promotion of Regional Science and Technology. Press Release. Ministry of Science, ICT and Future Planning: Gwacheon.

MSIP (2014a) *Science and Technology Yearbook 2013*. Ministry of Science, ICT and Future Planning: Gwacheon.

MSIP and KISTEP (2014) *Government Research and Development Budget Analysis in the 2014 Financial Year*. Ministry of Science, ICT and Future Planning and Korea Institute of Science and Technology Evaluation and Planning: Seoul.

MSIP (2014b) *Survey of Research and Development in Korea 2013*. Ministry of Science, ICT and Future Planning. Gwacheon.

MSIP (2013b) *Statistical Report on the Technology Trade on Korea in Accordance with the OECD Technology Balance of Payments Manual*. Ministry of Science, ICT and Future Planning: Gwacheon.

MSIP (2013c) *Survey of Research and Development in Korea* 2012. Ministry of Science, ICT and Future Planning: Gwacheon.

NSTC (2013a) *Third Basic Plan for Science and Technology, 2013–2017*. National Science and Technology Council: Seoul.

NSTC (2013b) *Science and Technology Yearbook 2012.* National Science and Technology Council: Gwacheon.

NSTC (2012) *Science and Technology Yearbook 2011*. National Science and Technology Council: Gwacheon.

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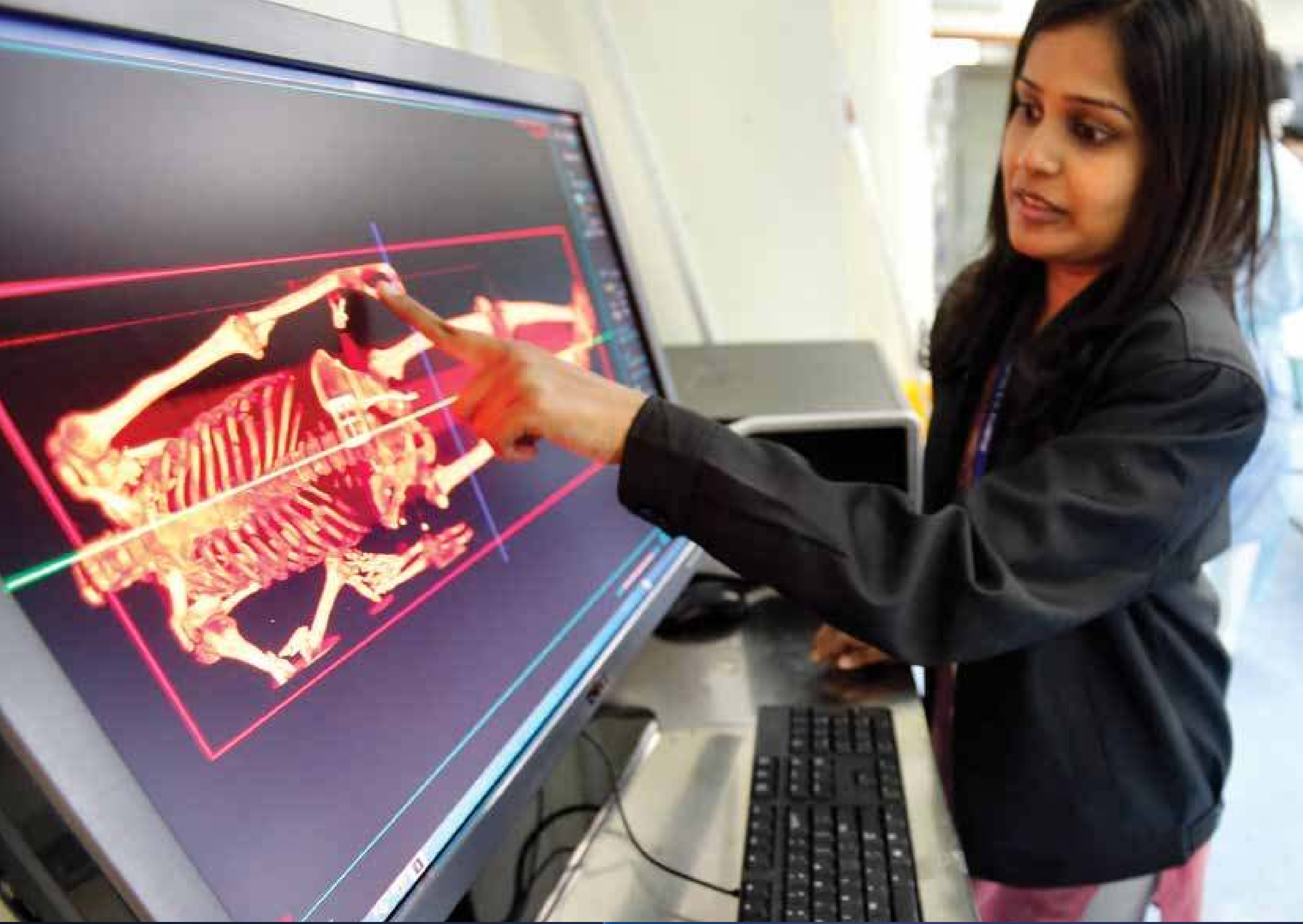


Accountability and effective monitoring [of innovation] is a must to ensure that investment yields a desirable rate of return.

Rajah Rasiah and **V.G.R. Chandran**

Dr Kastoori Karupanan demonstrates the Digital Autopsy at a mortuary in Kuala Lumpur Hospital. This forensic application creates a three-dimensional image that enables a virtual body to be viewed and dissected in high definition.
Photo: © Bazuki Muhammad/Reuters

26 · Malaysia

Rajah Rasiah and V.G.R. Chandran

INTRODUCTION

Stable economic growth but challenges lie ahead

The Malaysian economy grew by 4.1% per year on average between 2002 and 2013, pausing only briefly in 2009 at the height of the global financial crisis (Figure 26.1). The rapid return to positive growth in 2010 can be at least partly attributed to the two stimulus packages adopted by the government in November 2008 and March 2009.

Malaysia was an early convert to globalization. Since the launch of export-oriented industrialization in 1971, multinational corporations have relocated to Malaysia, fuelling a rapid expansion in manufactured exports that has helped turn the country into one of the world's leading exporters of electrical and electronics goods. In 2013 alone, Malaysia accounted for 6.6% of world exports of integrated circuits and other electronic components (WTO, 2014).

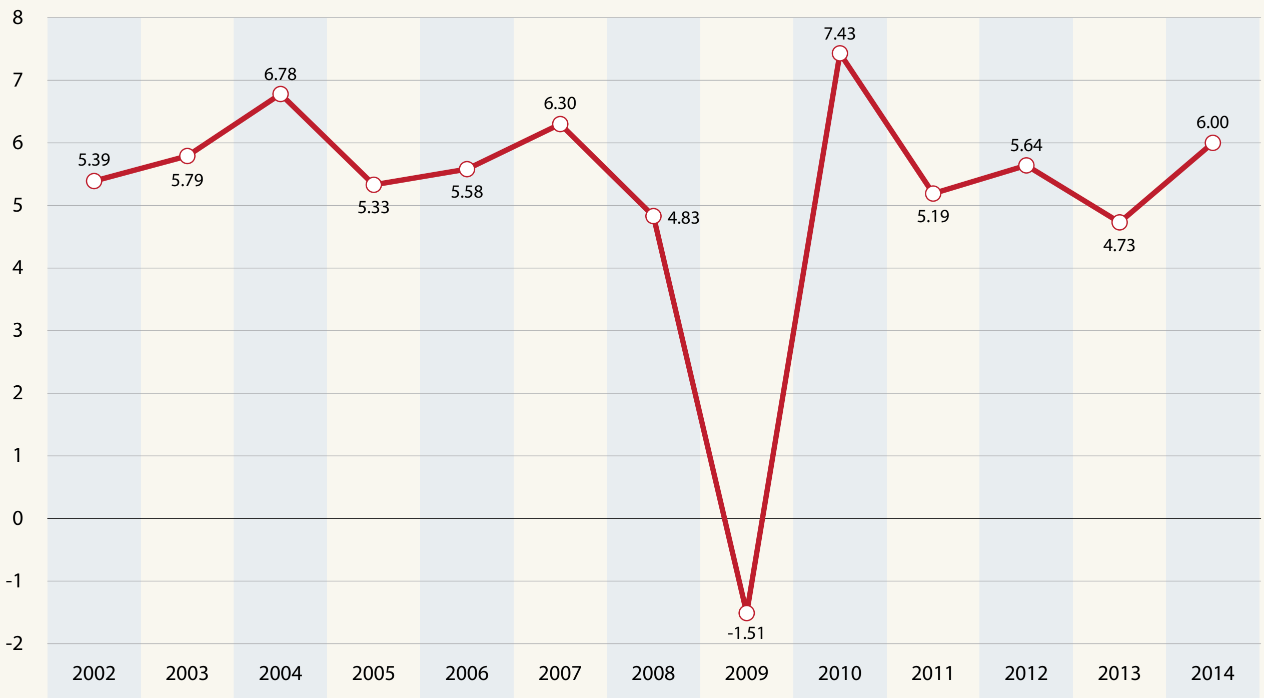
Rapid growth and the consequential tightening of the labour market led the Malaysian government to focus from the 1990s onwards on a shift from a labour-intensive economy to an innovation-intensive one. This goal is encapsulated in *The Way Forward* (1991), which fixes a target of achieving high-income status by 2020. Whereas Malaysia has done remarkably well over the past two years in terms of structural reform, several areas still require attention if the country is to achieve its goal. We shall now examine these areas one by one.

The rapid expansion of exports in electronics from the 1970s onwards has turned Malaysia into a major hub for the production of high-tech goods. Today, Malaysia is highly integrated in global trade, with manufacturing contributing over 60% of its exports. Half of these exports (49%) were destined for the East Asian market[1] in 2010, compared to just 29% in 1980. Over the past 15 years or so, the share of manufacturing in GDP has gradually declined as a natural consequence of the concomitant growth in services as a corollary of greater development. Modern manufacturing and services are deeply intertwined, as high-tech industries often have a massive services component. The development of the services sector is thus not, in itself, a cause for concern.

More worrying is the fact that the shift towards services has neglected the development of high-tech services. Moreover, although the volume of manufacturing has not declined, less value is being added to manufactured goods than before. As a consequence, Malaysia's trade surplus declined from

1. essentially China, Indonesia, Republic of Korea, the Philippines, Singapore, and Thailand

Figure 26.1: **GDP growth in Malaysia, 2002–2014 (%)**



Source: World Bank's World Development Indicators, June 2015

144 529 ringgits (MYR) in 2009 to MYR 91 539 in 2013 and Malaysia has been losing ground in high-tech exports. High-tech manufacturing has stagnated in absolute terms in recent years and its share of global added value has slipped from 0.8% in 2007 to 0.6% in 2013. Over the same period, Malaysia's global share of high-tech exports (goods and services) has contracted from 4.6% to 3.5% (WTO, 2014). The contribution of high-tech industries to national GDP has likewise dropped.

Malaysia also needs to reduce its reliance on oil and gas extraction. In 2014, oil and gas contributed nearly 32% of government revenue. Although natural gas represented about 40% of Malaysia's energy consumption in 2008, there have been gas shortages since 2009, owing to the combination of a declining domestic gas supply and rising demand. To compound matters, the sharp drop in global oil prices between July and December 2014 forced the government to cut expenditure in January 2015 to maintain its budget deficit at 3%. A recent budget review indicates that Malaysia will not be able to rely on its natural resources to propel itself towards high-income status by 2020.

Rising inequality is a growing concern in Malaysia, with the disparity between the top 20% income-earners and the bottom 40% widening. The government's Subsidy Rationalization Programme, which had first been rolled out in 2010 with little effect, moved into high gear in 2014 with three consecutive increases in natural gas prices in a single year. The removal of energy subsidies, coupled with the introduction of a general sales tax on consumer goods in April 2015, is expected to increase the cost of living. The four out of ten Malaysians in the lowest income bracket are also increasingly exposed to social and environmental risks. The incidence of dengue increased by 90% in 2013 over the previous year, for instance, with 39 222 recorded cases, in a trend which may be linked to deforestation and/or climate change. The rising crime rate is another concern.

Although Malaysia remains committed to reducing its carbon emissions by 40% by 2020 over 2012 levels, as pledged by the Malaysian prime minister at the climate summit in Warsaw in 2013, it faces growing sustainability challenges. In January 2014, Selangor, the most developed of Malaysia's federated states, experienced water shortages. These were not caused by lack of rainfall – Malaysia lies in the tropics – but by high pollution levels and the drying of reservoirs as a consequence of overuse. Land clearing and deforestation remain major concerns, causing landslides and population displacements. Malaysia is the world's second-biggest producer of palm oil after Indonesia, the two countries contributing about 86% of all palm oil in 2013, according to the World Wildlife Fund's 2013 Palm Oil Buyer's Scoreboard. Since the 1990s, palm oil exports have represented the third-largest category of Malaysian exports after fossil fuels (petroleum and gas) and electronics. About 58% of Malaysia remained forested in 2010. With the government having committed to preserving at least half of all land as primary forest, Malaysia has little latitude to expand the extent of land already under cultivation. Rather, it will need to focus on improving productivity (Morales, 2010).

Avoiding the middle-income trap

The Najib Razak coalition government came to power in 2009 before being re-elected in 2013. The government estimates that 6% annual growth is necessary to reach high-income status by 2020, which is somewhat higher than the average for the previous decade. A greater focus on innovation will be necessary to reach this goal.

One of the first schemes introduced by the current administration was the Economic Transformation Programme (ETP) in 2010, which contributes to the National Transformation Programme (2009). The ETP laid the foundations for the introduction of the *Tenth Malaysia Plan* (2011–2015) in 2010. The ETP seeks to strengthen industrial competitiveness, raise investment and improve governance, including public-sector efficiency. As much as 92% of this programme is to be financed by the private sector. The programme focuses on 12 growth areas:

- Oil, gas and energy;
- Palm oil and rubber;
- Financial services;
- Tourism;
- Business services;
- Electronics and electrical goods;
- Wholesale and retail;
- Education;
- Health care;
- Communications, content and infrastructure;
- Agriculture; and
- Greater Kuala Lumpur/Kelang Valley.

The programme identifies six Strategic Reform Initiatives to drive competitiveness and create a business-friendly environment: competition, standards and liberalization; public finance reform; public service delivery; narrowing disparities; the government's role in business; and human capital development. The education component of the *Economic Transformation Programme* focuses on four main areas: Islamic finance and business; health sciences; advanced engineering; and hospitality and tourism.

ISSUES IN STI GOVERNANCE

Growing expectations of S&T for inclusive development

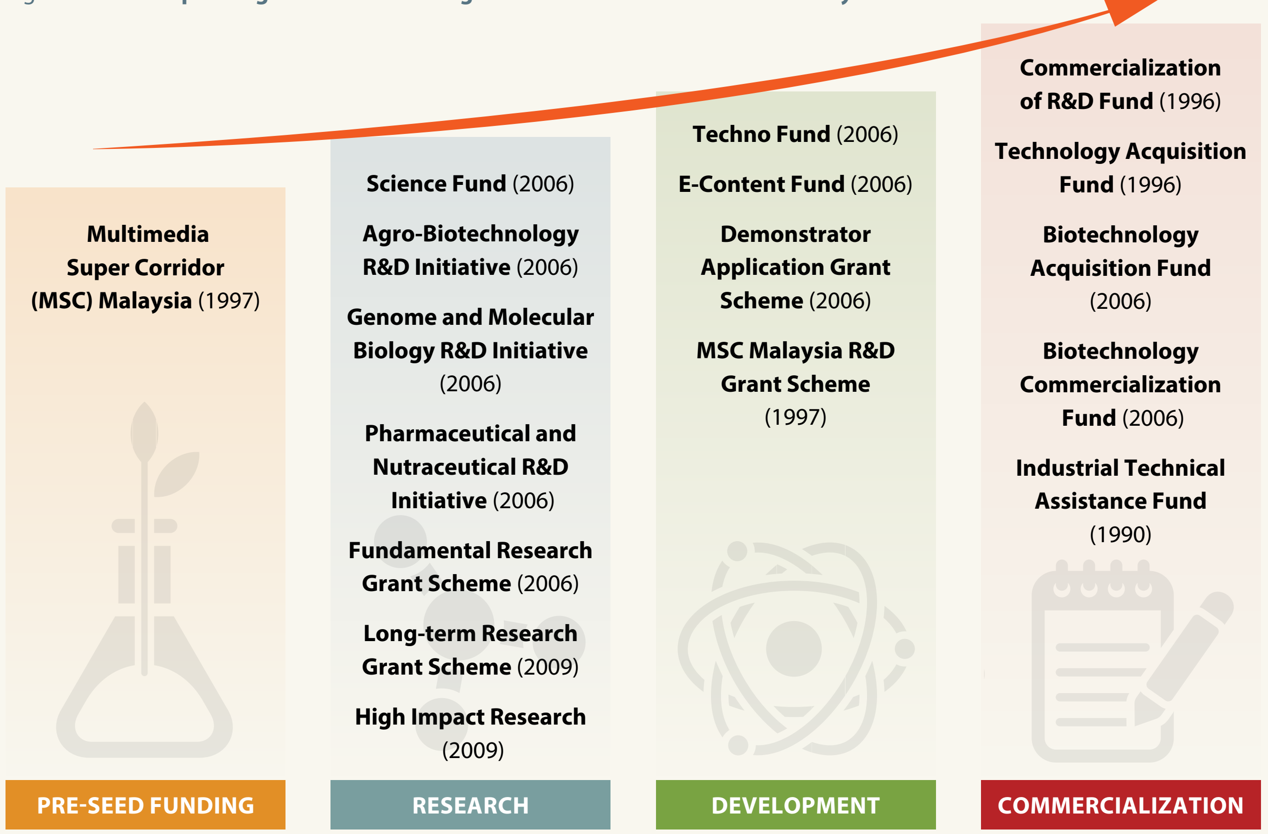
Despite significant progress since the 1970s, Malaysia is not yet in the same league as dynamic Asian economies such as the Republic of Korea, with which it is often compared. Governance issues and weak institutional capabilities in STI figure at the top of the list of current shortcomings. In addition, budget deficits have recently started putting pressure on public investment levels, including research and development (R&D). In particular, recurrent crises have pushed the government to shift expenditure towards addressing socio-economic problems.

Innovation for inclusive development has risen in the public policy agenda and is currently being widely discussed in Malaysia, in a context of low farm productivity, increasing health-related problems, natural disasters, environmental problems and even monetary inflation. In 2014, the government launched transdisciplinary research grants with the objective of including societal benefits among the performance criteria at Malaysia's research universities and providing incentives to promote science in support of poverty alleviation and sustainable development.

Effective inter-agency co-ordination across policy boundaries will obviously be necessary to develop innovative solutions to the problems outlined above. The Ministry of Science, Technology and Innovation (MoSTI) and the Ministry of Education are the principal drivers of Malaysia's national innovation system. There seems to be some agreement that applied research is the purview of MoSTI, whereas basic research falls under the Ministry of Education, but there is no mechanism for co-ordinating basic and applied research. Also, MoSTI monitors innovation through surveys, the provision of grants and evaluations but it lacks the industrial exposure to co-ordinate industrial grants effectively, a failing which is evident from the absence of an effective performance criterion for some government grant programmes, including the TechnoFund (Figure 26.2). It is important that a body closer to industry, such as the Ministry of International Trade and Industry (MoITI) or its sub-organ, the Malaysian Industrial Development Authority (MIDA), be entrusted with this role. Accountability and effective monitoring is a must to ensure that investment yields a desirable rate of return.

Despite the long-standing role of government in funding R&D programmes, there is currently no systematic approach to R&D programme appraisal and monitoring. Remedying this

Figure 26.2: **Examples of government funding instruments for innovation in Malaysia**



Note: The year of the fund's creation is given in brackets

Source: Adapted from MoSTI (2013)

oversight would require introducing a legal framework and engaging the stakeholders in the early stages of designing performance monitoring and assessment criteria. Indeed, an independent monitoring body could provide greater accountability and transparency over the disbursement and collection of R&D funds and reduce duplication.

There has been some recognition of the need to co-ordinate STI better, in particular as concerns research and commercialization of the results. For example, the National Science Research Council presented a proposal in 2014 to establish a central independent agency to co-ordinate R&D. The agency's mandate would incorporate technology foresight, among other tasks, as well the monitoring, evaluation and management of R&D.

Many issues have resurfaced in current policy

The government's focus on STI dates back to the launch of the *First Science and Technology Policy* in 1986. This was followed by an *Action Plan for Industrial Technology Development* in 1991 to stimulate the development of strategic and knowledge-intensive industries, as well as by the creation of intermediary organizations such as training centres, universities and research laboratories to propel this development. It is the *Second Science and Technology Policy* (2002–2010), however, which is considered the first comprehensive formal national policy with specific strategies and action plans to set the STI agenda.

The current *Third National Science and Technology Policy* (2013–2020) emphasizes the generation and utilization of knowledge; talent development; energizing innovation in industry; and improving the governance framework for STI to support innovation. Nevertheless, many of the issues targeted in the first two policies have resurfaced in the third policy, implying that the objectives fixed in the previous policies have not been achieved; these issues include the diffusion of technology, the private sector's contribution to R&D and innovation, commercialization, monitoring and evaluation.

Without business R&D, 2020 target will not be reached

Without a doubt, R&D is contributing far more to the country's development than even a decade ago. Between 2008 and 2012, gross domestic expenditure on R&D (GERD) rose from 0.79% to 1.13% of GDP (Figure 26.3). This is all the more remarkable in that GDP grew steadily over the same period. Despite this progress, Malaysia still lags behind Singapore or the Republic of Korea for this indicator; the gap is particularly wide when it comes to business expenditure on R&D (BERD). In 2012, Malaysia's BERD/GDP ratio stood at 0.73%, compared to 1.2% in Singapore and 3.1% in the Republic of Korea. Malaysia is targeting a 2.0% GERD/GDP ratio by 2020; whether or not it reaches this target will depend largely upon the dynamism of the business enterprise sector.

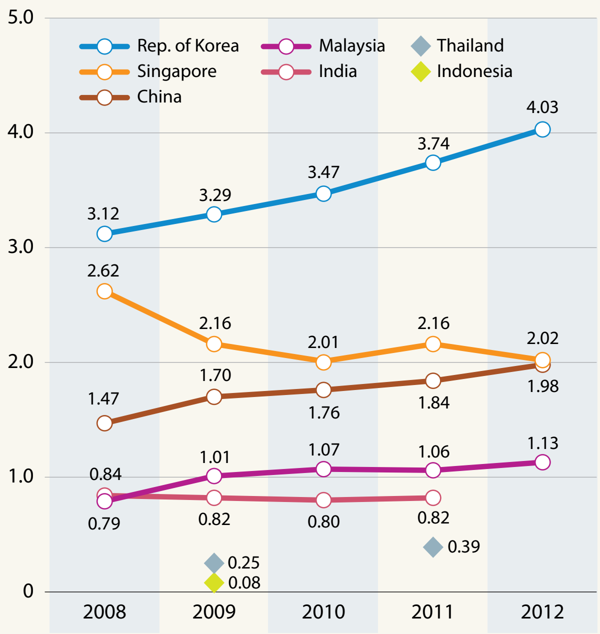
While private sector participation in R&D has risen considerably since 2005, in particular, its share is still quite low in comparison with dynamic Asian economies. For example, between 2006 and 2011, a total of 25 423 ICT patents were filed in the USA by Koreans, compared to a meagre 273 by Malaysians (Rasiah *et al.*, 2015a, 2015b).

R&D spillovers have not been significant, despite the strong presence of multinational corporations in Malaysia. This is due to the lack of a critical mass of R&D infrastructure, especially as concerns human capital and laboratories specializing in frontier R&D at research universities and government-owned institutions (OECD, 2013; Rasiah, 2014).

The involvement of multinational corporations in frontier R&D is still limited in Malaysia, so pro-active measures will be required to develop this activity (Rasiah *et al.*, 2015a). R&D conducted by both national and foreign firms is largely confined to product proliferation and problem-solving. For example, in the ICT industry, no firm is engaged in R&D targeted at miniaturizing ICT nodes or in expanding wafer diameters. Innovative activity tends to be limited to the transfer and diffusion of technology through intra-industry trade, particularly in the country's free trade zones. This constant focus on production-type operations will only be able to contribute to incremental innovation (Rasiah, 2010). In 2012, a group of multinationals established a platform to promote collaborative R&D; although this is a step in the right direction, it is too early at this stage to assess its success (Box 26.1).

Figure 26.3: **GERD/GDP ratio in Malaysia, 2008–2012**

Other countries are given for comparison



Source: UNESCO Institute for Statistics, May 2015

Box 26.1: A multinational platform to drive innovation in electrical goods and electronics

To address the shortcomings of the local innovation ecosystem, a group of multinational corporations have created their own platform for Collaborative Research in Engineering, Science and Technology (CREST). Established in 2012, this trilateral partnership involving industry, academia and the government strives to satisfy the research needs of electrical and electronics industries, which employ nearly 5 000 research scientists and engineers.

This platform was initiated by ten leading electrical and electronic companies: Advanced Micro Devices, Agilent Technologies, Altera, Avago Technologies, Clarion, Intel, Motorola Solutions, National Instruments, OSRAM and Silterra. These companies generate close to MYR 25 billion (*circa* US$ 6.9 billion) in annual revenue and spend nearly MYR 1.4 billion on R&D. Government grants have been utilized extensively by these multinational firms since 2005 (Rasiah *et al*, 2015a).

The Northern Corridor Implementation Authority, Khazanah Nasional, University of Malaya and University of Science Malaysia work closely with CREST. Besides R&D, the focus is on talent development, the ultimate aim being to help the industry add greater value to its products.

Source: www.crest.my

The current gaps in knowledge, capability and financing also make it harder for small and medium-sized enterprises (SMEs) to undertake R&D. Most of the SMEs that work as subcontractors for multinational firms have remained confined to the role of original equipment manufacturers. This prevents them from participating in original design and original brand manufacturing. SMEs thus need greater support in accessing the requisite knowledge, capability and financing. One key strategy is to connect SMEs to the incubation facilities in the country's science and technology parks.

Losing ground in high-tech exports

While discovery and patenting are crucial for Malaysia's export-oriented competitiveness and growth strategy, there still seems to be little return on investment in R&D (Chandran and Wong, 2011). Although patent applications with the Malaysian patent office have increased steadily over the years (7 205 in 2013), they lag far behind those of competitors such as the Republic of Korea (204 589 in 2013), according to the World Intellectual Property Organization. Moreover, domestic applications seem to be of lower quality in Malaysia, with a cumulative grants-to-application ratio of 18% between 1989 and 2014, against 53% for foreign applicants over the same period. In addition, academic or public research organizations in Malaysia appear to have a limited ability to translate research into intellectual property rights. The Malaysian Institute of Micro-electronic Systems (MIMOS),[2] Malaysia's forefront public R&D institute, which was corporatized in 1992, contributed 45–50% of Malaysia's patents filed in 2010 (Figures 26.4 and 26.5) but the low citations that have emerged from those patents suggest that the commercialization rate is low.

Of some concern is that Malaysia's global share of high-tech density has declined over the years and that the contribution of high-tech industries to manufacturing exports has dropped considerably since 2000 (Table 26.1).

2. This institute was attached to the Office of the Prime Minister until its corporatization.

Table 26.1: **Intensity of high-tech industries in Malaysia, 2000, 2010 and 2012**

Other countries are given for comparison

	World share, 2000 (%)	World share, 2010 (%)	World share, 2012 (%)	Share of manufacturing exports, 2000 (%)	Share of manufacturing exports, 2010 (%)	Share of manufacturing exports, 2012 (%)
Malaysia	4.05	3.33	3.08	59.57	44.52	43.72
Thailand	1.49	1.92	1.70	33.36	24.02	20.54
Indonesia	0.50	0.32	0.25	16.37	9.78	7.30
India	0.18	0.57	0.62	6.26	7.18	6.63
Korea, Rep.	4.68	6.83	6.10	35.07	29.47	26.17
Brazil	0.52	0.46	0.44	18.73	11.21	10.49
Japan	11.10	6.86	6.20	28.69	17.97	17.41
Singapore	6.37	7.14	6.44	62.79	49.91	45.29
China	3.59	22.82	25.41	18.98	27.51	26.27
United States	17.01	8.18	7.48	33.79	19.93	17.83
European Union	33.82	32.31	32.00	21.40	15.37	15.47

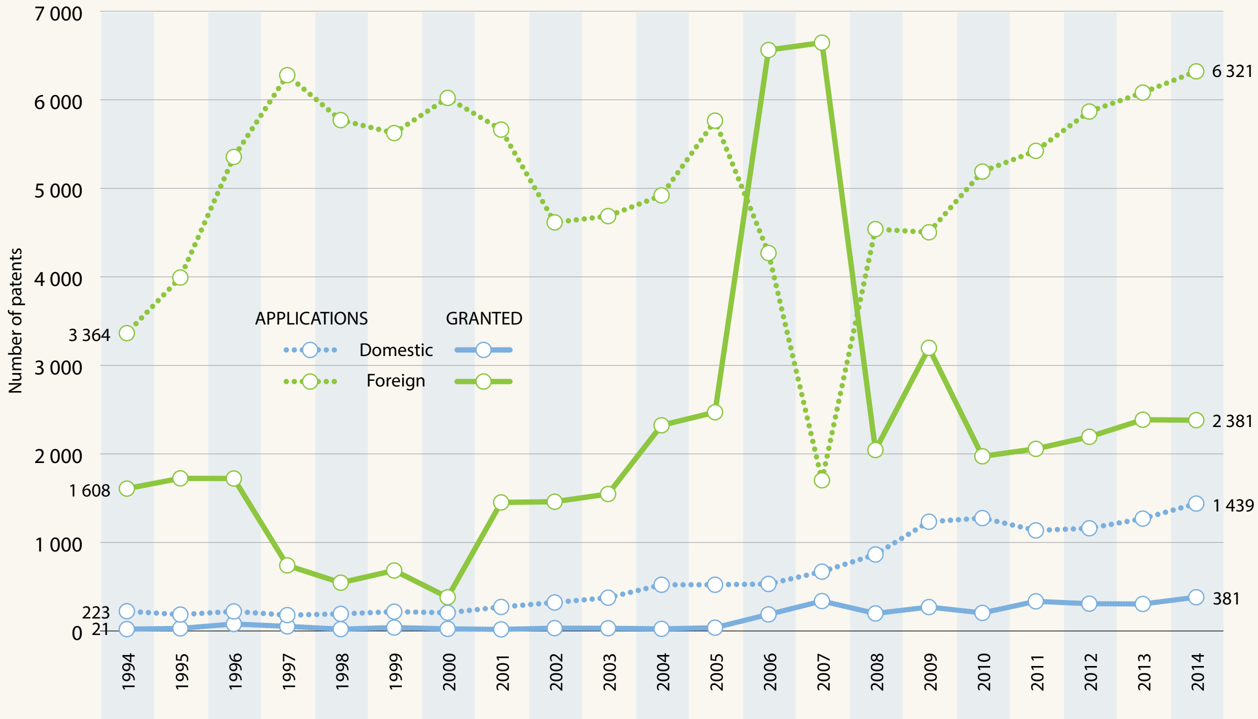
Source: World Bank's World Development Indicators, April 2015

A need to increase the rate of return on R&D

As argued by Thiruchelvam *et al.* (2011), there is still little return on investment in R&D, despite the added emphasis on pre-commercialization and commercialization in the *Ninth Malaysia Plan* (2006–2010). This low commercialization rate can largely be attributed to a lack of university–industry collaboration, rigidities in research organizations and problems with co-ordinating policies. Universities seem to confine the commercialization of their research results to specific areas, such as health and ICTs.

In 2010, the government established the Malaysian Innovation Agency to spur the commercialization of research.

Figure 26.4: **Patent applications and granted patents in Malaysia, 1994–2014**

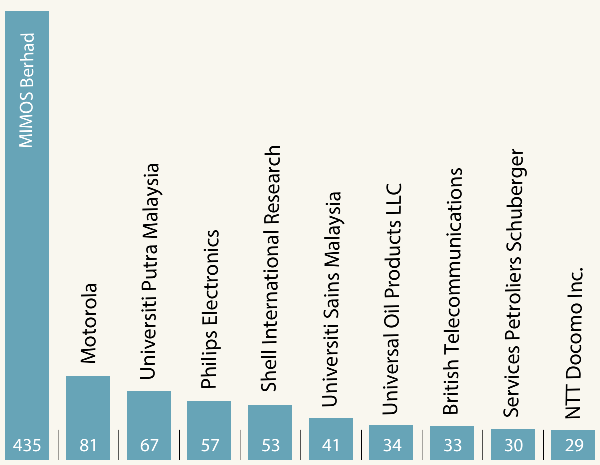


Note: The data for 2014 are for January–November.

Source: Malaysian Patent Office, March 2014

The Malaysian Technology Development Corporation has also made a concerted effort to help companies translate commercialization grants into viable products. On the whole, however, the results have not been encouraging. Success in commercialization has been limited to a handful of organizations, namely, the Malaysian Palm Oil Board (Box 26.2), Rubber Research Institute of Malaysia, Universiti Putra Malaysia and Universiti Sains Malaysia.

Figure 26.5: **Top patent assignees in Malaysia, 2010**



Source: Compiled from PCT database

Five years after its inception, the Malaysian Innovation Agency has made a limited impact on commercialization thus far, owing to the unclear delineation of its role in relation to MoSTI and its limited resources. Nevertheless, there is some evidence to suggest that the agency is beginning to play a catalytic role in driving commercialization and an innovative culture, especially as regards innovation beyond the hardware industry, which is where firms[3] offering services, such as airline services, are active. The agency still needs to strengthen its ties with other agencies and ministries, however, to ensure the effective implementation of government strategies and plans. Some consolidation of the various agencies and ministries involved in STI would also be desirable, in order to facilitate effective collective action while preserving competition within the system.

The numerous science and technology parks in Malaysia benefit from government incentives designed to stimulate commercialization. These include the Long Research Grants Scheme, Fundamental Research Grants Scheme, the TechnoFund and E-science Fund (Figure 26.2). Although the first two grant schemes focus largely on basic research,

3. A survey by the Malaysian Science and Technology Information Centre in 2012 found that the great majority of firms reporting product innovation had recourse to in-house R&D – 82% in manufacturing and 80% in services – whereas most of the remainder (17% and 15% respectively) conducted R&D jointly with other firms (MASTIC, 2012).

applicants are also encouraged to commercialize their findings. The TechnoFund and E-science Fund, on the other hand, focus exclusively on commercialization. There is a serious need to assess their role and success rate in promoting commercialization. There is also a need to strengthen institutional capabilities in technoparks and to ensure that these public goods effectively target the commercialization of knowledge, with a minimum rate of failure in translating these grants into products and services worth commercializing, which is known as a minimum dissipation of rents (Rasiah *et al.*, 2015a). Most multinational corporations established in Malaysia specialize in ICTs and are located in the Kulim High Tech Park (Kedah) and Penang (Table 26.2).

In 2005, MoSTI extended the research grants it had been offering to domestic firms since 1992 to multinationals (Rasiah *et al.*, 2015b). As a consequence, the number of patents filed in the USA by foreign firms specializing in integrated circuits rose from 39 over the 2000–2005 period to 270 over 2006–2011. As in Singapore, the focus of these research grants is on both basic and applied research (Figure 26.2). However, whereas, in the case of Singapore, university–industry linkages and science parks have largely determined the success of such schemes, these relays are still evolving in Malaysia (Subramoniam and Rasiah, forthcoming).

Box 26.2: **The Malaysian palm oil industry**

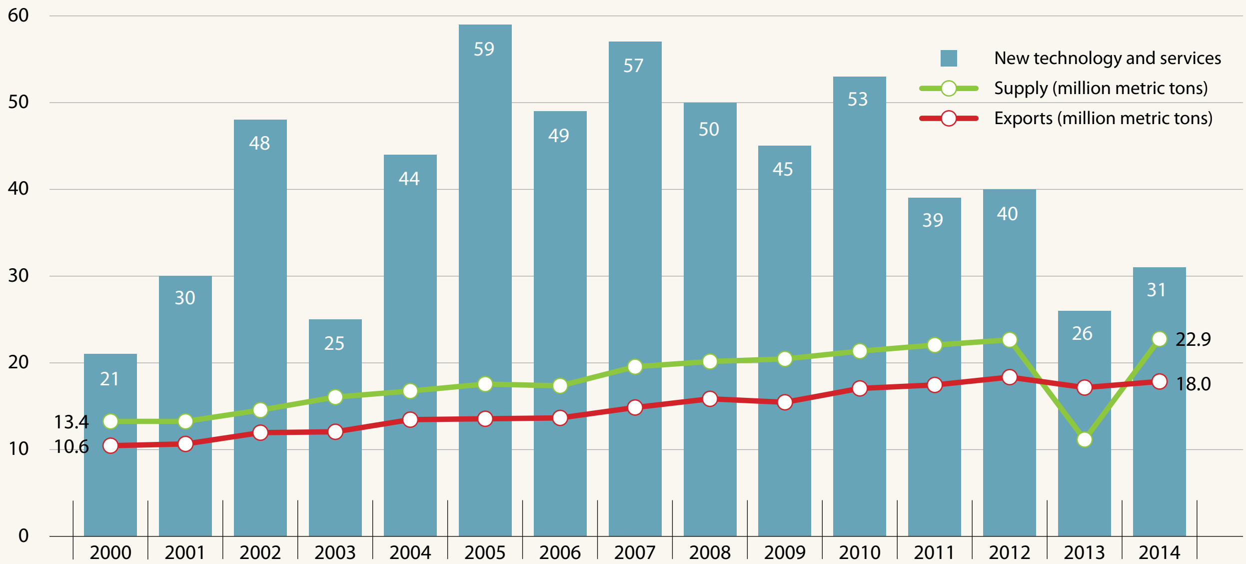
The oil palm industry contributes to R&D through a cess fund managed by the Malaysian Palm Oil Board (Figure 26.6). This entity derives its funding mainly from the cess (or tax) imposed on the industry for every tonne of palm oil and palm kernel oil produced. In addition, the Malaysian Palm Oil Board receives budget allocations from the government to fund development projects and for research projects approved by the Long-term Research Grants scheme. Through the cess, the palm oil industry thus contributes strongly to funding the research grants provided by the Malaysian Palm Oil Board; these grants amounted to MYR 2.04 billion (*circa* US$ 565 million) over the 2000–2010 period.

The Malaysian Palm Oil Board publishes several journals, including the *Journal of Oil Palm Research*, and oversees the Tropical Peat Research Institute, which conducts research into the effects of planting palm oil on peat land and on the transformation of peat into a greenhouse gas once it reaches the atmosphere.

The Malaysian Palm Oil Board supports innovation in areas such as biodiesel and alternate uses for palm biomass and organic waste. Its research into biomass has led to the development of wood and paper products, fertilizers, bio-energy sources, polyethylene sheeting for use in vehicles and other products made of palm biomass. Between 2013 and 2014, the Malaysian Palm Oil Board recorded a rise in the number of new technologies commercialized from 16 to 20.

The Malaysian Palm Oil Board resulted from the merger of the Palm Oil Research Institute of Malaysia and the Palm Oil Registration and Licensing Authority in 2000 by act of parliament.

Figure 26.6: **Key indicators for Malaysia's oil palm industry, 2000–2014**



Source: Malaysian Palm Oil Board (2015); United Nations' COMTRADE database

Source: www.mpob.gov.my

Table 26.2: **Semiconductor firms in Penang and Kedah with R&D and/or chip design, 2014**

	Origin	Year	Structure	Main activity	Upgrading
Advanced Micro Devices	USA	1972	Integrated device manufacturing	Assembly and testing	Has in-house R&D to support assembly and testing
Altera	USA	1994	Integrated device manufacturing	Design centre	Has in-house R&D to support design
Avago Technology	Singapore	1995	Integrated device manufacturing	Assembly and testing	Has in-house R&D to support assembly and testing of analogue, mixed-signal and opto-electronic components
Fairchild	USA	1971	Integrated device manufacturing	Assembly and testing	Started as national Semiconductor; has in-house R&D to support assembly and testing
Globetronics	Malaysia	1991	Fabless	Die sawing, sorting, plating and assembly of LEDs	Has R&D to support production
Infineon	Germany	2005	Integrated device manufacturing	Wafer fabrication	Engaged in '8' powerchip fabrication; has in-house R&D to support wafer fabrication
Intel	USA	1972	Integrated device manufacturing	Assembly and testing	Has in-house R&D to support assembly and testing
Intel	USA	1991	Integrated device manufacturing	Design centre	Integrated circuit design; site was previously used by Intel Technology from 1979 onwards; Has in-house support R&D
Marvell Technology	USA	2006	Fabless	Design centre	Has in-house support R&D
Osram	Germany	1972	Integrated device manufacturing	Wafer fabrication	Established first as Litronix in 1972; acquired by Siemens Litronix in 1981; changed to Osram Opto-electronics in 1992; upgraded from assembly and testing to include wafer fabrication in 2005; has in-house support R&D
Renesas Semiconductor Design	Japan	2008	Integrated device manufacturing	Design centre	Specializes in design; has in-house support R&D
Renesas Semiconductor Malaysia	Japan	1972	Integrated device manufacturing	Assembly and testing	Upgraded to include R&D support since 1980 and has expanded R&D since 2005
Silterra	Malaysia	1995	Foundry	Wafer fabrication	Founded as Wafer Technology Malaysia but renamed Silterra in 1999; has in-house R&D to support wafer fabrication

Note: Fabless refers to the design and sale of hardware devices and semiconductor chips while outsourcing the fabrication of these devices to a semiconductor foundry.

Source: Rasiah *et al.* (2015a)

University reform has boosted productivity

In 2006, the government introduced a *Higher Education Strategic Plan Beyond 2020* which established five research universities over the next three years and raised government funding for higher education. For more than a decade, public expenditure on higher education has accounted for about one-third of the education budget (Thiruchelvam *et al.*, 2011). Malaysia spends more on higher education than any of its Southeast Asian neighbours but the level of commitment had slipped somewhat between 2003 and 2007 from 2.6% to 1.4% of GDP. The government has since restored higher education spending to earlier levels, as it accounted for 2.2% of GDP in 2011 (see Figure 27.5).

The meteoric rise in scientific publications since 2009 (Figure 26.7) is a direct consequence of the government's decision to promote excellence at the five research universities, namely: Universiti Malaya, Universiti Sains Malaysia, Universiti Kebangsaan Malaysia, Universiti Putra Malaysia and Universiti Teknologi Malaysia. In 2006, the government decided to provide grants for university research. Between 2008 and 2009, these five universities received an increase of about 71% in government funding (UIS, 2014).

Along with this targeted R&D funding, key performance indicators were changed for the teaching staff, such as by making the publication record of staff an important criterion for promotion. In parallel, the Ministry of Higher Education (MoHE) designed and implemented a performance measurement and reporting system for universities in 2009, which were also entitled to conduct self-assessments and self-monitoring.

One spin-off from the increase in R&D funding by MoHE was that the share of basic research rose from 11% of GERD in 2006 to 34% in 2012. The bulk of the budget still goes towards applied research, which represented 50% of GERD in 2012. Between 2008 and 2011, the lion's share of scientific publications focused on engineering (30.3%), followed by biological sciences (15.6%), chemistry (13.4%), medical sciences (12.0%) and physics (8.7%).

At the same time, Malaysia still has some way to go to improve the impact of its scientific production. At 0.8 citations per paper in 2010, Malaysia trails the OECD (1.08) and G20 (1.02) averages, as well as neighbours such as Singapore, the Republic of Korea or Thailand (see Figure 27.8). It is close to the bottom of the league in Southeast Asia and Oceania for the citation rate and share of its scientific production among the 10% most cited papers between 2008 and 2012 (Figure 27.8).

Although more objective performance measures have been introduced into the university system to assess the outcome of research funding and its impact on socio-economic and sustainable development, a similar system is still missing for public research institutes. In 2013, the government launched an outcome-based approach to assessing public investment in R&D which includes funding for projects on sustainability and ethical issues. The University of Malaya Research Grant, among others, has since absorbed this criterion by including humanities and ethics, social and behavioural sciences and sustainability sciences among its priority areas for research funding.

TRENDS IN HUMAN RESOURCES

Strong growth in researcher intensity

The number of full-time equivalent (FTE) researchers in Malaysia tripled between 2008 and 2012 from 16 345 to 52 052, resulting in a researcher intensity of 1 780 per million population in 2012 (Figure 26.8). Although this intensity is well above the global average, it cannot match that of the Republic of Korea or Singapore.

The government is eager to develop endogenous research capabilities in order to reduce the country's reliance on industrial research undertaken by foreign multinational companies. The *Higher Education Strategic Plan Beyond 2020* fixed the target of producing 100 000 PhD-holders by 2020, as well as increasing the participation rate in tertiary education from the current 40% to 50%. The 100 000 PhD-holders are to be trained locally, overseas and through split programmes with foreign universities (UIS, 2014). As part of this effort, the government has allocated MYR 500 million (*circa* US$ 160 million) to financing graduate students, a measure which helped to double enrolment in PhD programmes between 2007 and 2010 (Table 26.3).

Table 26.3: **University enrolment in Malaysia, 2007 and 2010**

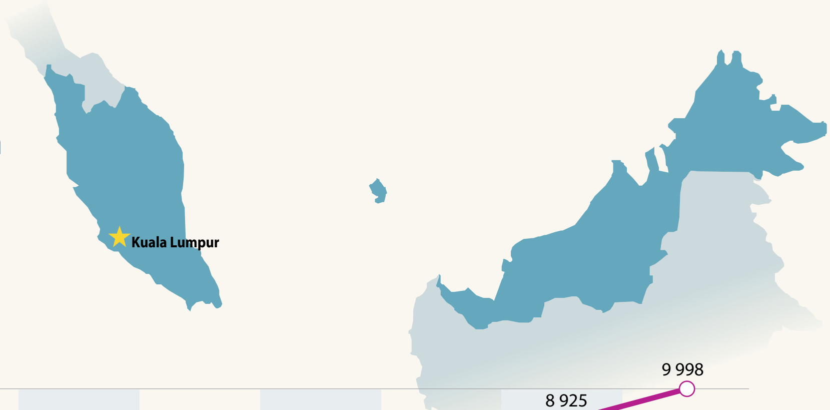
	Total enrolment ('000s) 2007	Private (%) 2007	Total enrolment ('000s) 2010	Private (%) 2010
Bachelor's degree	389	36	495	45
Master's degree	35	13	64	22
PhD	11	9	22	18

Source: UIS (2014)

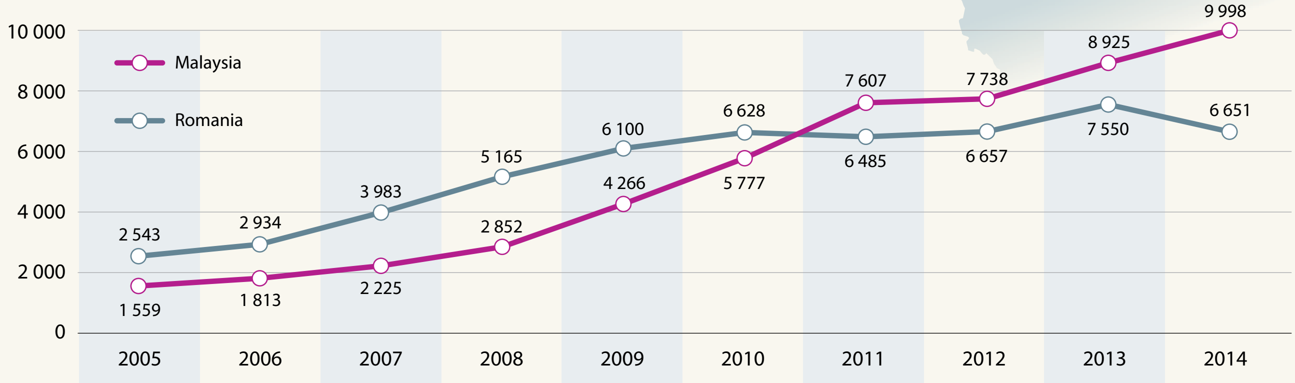
Singapore snaps up much of the diaspora

Despite the rise in tertiary students since 2007, brain drain remains a worry. Singapore alone absorbs 57% of the diaspora, the remainder opting for Australia, Brunei, the UK and USA. There is evidence to show that the skilled diaspora is now three times bigger than two decades ago, a factor which has reduced the human resource pool – and, no doubt, slowed progress in STI. In order to address this issue, the government has launched Talent Corp and a targeted Returning Expert Programme (MoSTI, 2009). Although 2 500 returnees have been approved for the incentive scheme since 2011, the programme is yet to make a big impact.

Figure 26.7: **Scientific publication trends in Malaysia, 2005–2014**



Malaysian publications have grown rapidly since 2005, overtaking those of similarly populated Romania



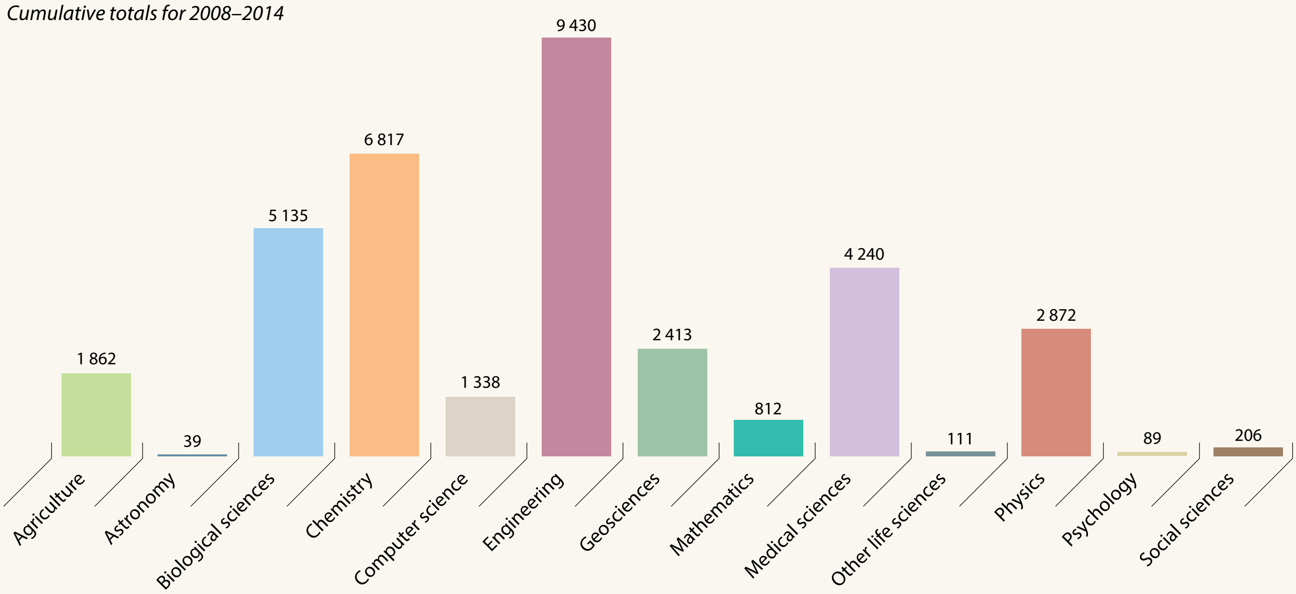
0.83
Average citation rate for Malaysian publications, 2008–2012; the OECD average is 1.08; the G20 average is 1.02

8.4%
Share of Malaysian papers among 10% most-cited, 2008–2012; the OECD average is 11.1%; the G20 average is 10.2%

46.4%
Share of Malaysian papers with foreign co-authors 2008–2014; the OECD average is 29.4%; the G20 average is 24.6%

Nearly half of Malaysian publications are in engineering or chemistry

Cumulative totals for 2008–2014



Note: The total by field excludes unclassified publications (11 799) between 2008 and 2014.

Malaysia's key scientific partner countries span four continents

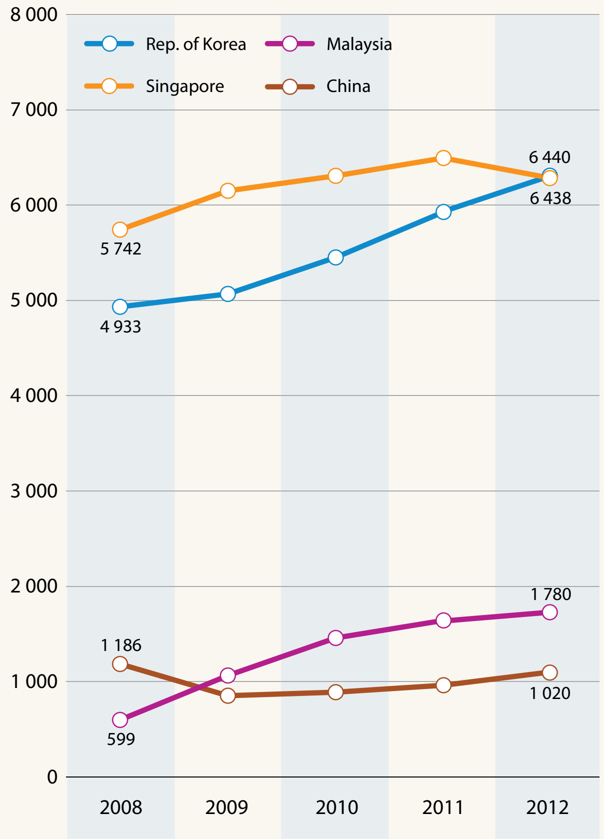
Main foreign partners, 2008–2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Malaysia	UK (3 076)	India (2 611)	Australia (2 425)	Iran (2 402)	USA (2 308)

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

Figure 26.8: **Researchers (FTE) per million population in Malaysia, 2008–2012**

Other countries are given for comparison



Source: UNESCO Institute for Statistics, May 2015

Strong growth in private and foreign students

Meanwhile, private universities are increasingly absorbing more undergraduate students than their public counterparts. Between 2007 and 2010, the share of students enrolled in a bachelor's programme at a private university rose from 37% to 45%. This is a consequence of the five leading research universities' growing focus on graduate education since 2009, accompanied by more competitive intake requirements, as well as the preference of some students for private universities where the use of English as a medium of communication is more common. Of note is that a much larger proportion of academic staff hold a master's or doctoral degree at public institutions (84%) than at private ones (52%) [UIS, 2014].

The government is increasing the number of international schools at primary and secondary levels to accommodate the needs of returnees and earn foreign exchange from non-Malaysian pupils. The target outlined in the *Economic Transformation Programme* (2010) is for there to be 87 international schools by 2020. Although there were 81 such schools by 2012, most of these establishments have small rolls: there were a total of 33 688 pupils in 2012, less than half the government target of 75 000 pupils by 2020. To close the gap, the government has embarked on an international promotional campaign.

In 2005, Malaysia adopted the target[4] of becoming the sixth-largest global destination for international university students by 2020. Between 2007 and 2012, the number of international students almost doubled to more than 56 000, the target being to attract 200 000 by 2020. Among member states of the Association of Southeast Asian Nations (ASEAN), Indonesian students were most numerous, followed by Thais. By 2012, Malaysia was one of the top ten destinations for Arab students; the upheaval caused by the Arab Spring has incited a growing number of Egyptians and Libyans to try their luck in Malaysia but there has also been a sharp rise in the number of Iraqis and Saudis. Particularly strong growth has also been observed among Nigerian and Iranian students (Figure 26.9).

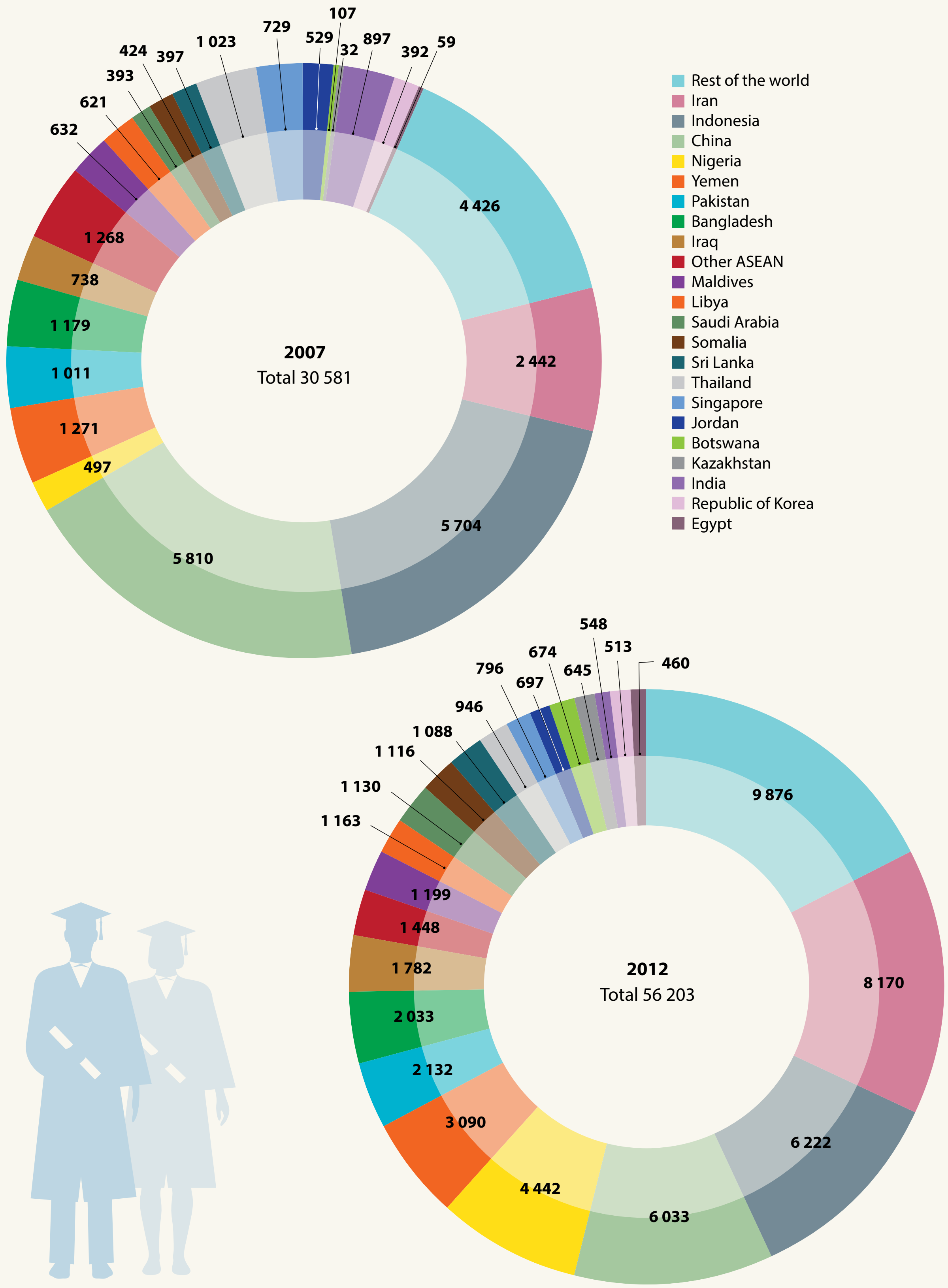
Concerns about the declining quality of education

The ratio between university students enrolled in fields related to science, technology, engineering and mathematics (STEM) and those enrolled in non-STEM disciplines has grown since 2000 from 25:75 to 42:58 (2013) and may soon reach the government's target of 60:40. There is evidence, however, that the quality of education has declined in recent years, including the quality of teaching. The results of the Programme for International Student Assessment (PISA) in 2012 show that Malaysian 15 year-olds perform below average in mathematics and scientific literacy. Indeed, Malaysia's score has declined significantly in some fields, with only one out of 100 Malaysian 15 year-olds being able to solve complex problems, in comparison to one out of five in Singapore, the Republic of Korea and Japan. In 2012, Malaysians also scored lower in knowledge acquisition (29.1) and utilization of knowledge (29.3) than teenagers in Singapore (62.0 and 55.4 respectively) or the average for all PISA participants (45.5 and 46.4 respectively).

A number of the education reforms implemented since 1996 have faced resistance from teachers. The most recent national education blueprint (2013–2025), adopted in 2012, aims to provide equal access to quality education, develop proficiency in the English and Malay languages and to transform teaching into a profession of choice. In particular, it seeks to leverage ICTs to scale up quality learning across Malaysia and improve the delivery capabilities of the Ministry of Education through partnerships with the private sector, in addition to raising transparency and accountability. A central goal will be to promote a learning environment that promotes creativity, risk-taking and problem-solving by both teachers and their pupils (OECD, 2013). As it takes time for education reforms to deliver results, consistent monitoring of these reforms will be the key to their success.

4. *See:* http://monitor.icef.com/2012/05/malaysia-aims-to-be-sixth-largest-education-exporter-by-2020

Figure 26.9: **Number of degree-seeking international students in Malaysia, 2007 and 2012**
By country of origin



Source: UNESCO Institute for Statistics, June 2015

TRENDS IN INTERNATIONAL CO-OPERATION

A Malaysian centre for South–South co-operation

When *ASEAN Vision 2020* was adopted in 1997, its stated goal was for the region to be technologically competitive by 2020. Although the focus of ASEAN has always been on the creation of a single market along the lines of the European model, leaders have long acknowledged that successful economic integration will hinge on how well member states manage to assimilate science and technology. The ASEAN Committee on Science and Technology was established in 1978, just eleven years after ASEAN was founded by[5] Indonesia, Malaysia, the Philippines, Singapore and Thailand. Since 1978, a series of action plans have been developed to foster co-operation among member states, in order to create a more even playing field in STI. These action plans cover nine programme areas: food science and technology; biotechnology; meteorology and geophysics; marine science and technology; non-conventional energy research; micro-electronics and information technology; materials science and technology; space technology and applications; and S&T infrastructure and the development of resources. Once the ASEAN Economic Community comes into effect in late 2015, the planned removal of restrictions to the cross-border movement of people and services should spur co-operation in science and technology and enhance the role of the ASEAN University Network (see Chapter 27).

In 2008, the Malaysian government established the International Centre for South–South Cooperation in Science, Technology and Innovation, under the auspices of UNESCO. The centre focuses on institution-building in countries of the South. Most recently, it ran a training course on the maintenance of infrastructure from 10 March to 2 April 2015, in collaboration with the Malaysian Highway Authority, Construction Industry Development Board, the Institution of Engineers Malaysia and the Master Builders Association Malaysia.

As far as bilateral co-operation is concerned, the Malaysian Industry–Government Group for High Technology (MIGHT) and the British government established the Newton-Ungku Omar Fund in 2015, which is being endowed with £ 4 million annually for the next five years by each government. In 2014, MIGHT also signed an agreement with Asian Energy Investment Pte Ltd, based in Japan, to create a fund management company called Putra Eco Ventures which would invest in efficient and renewable energy assets and businesses. Potential targets for funding are smart-grid and energy-saving technologies, as well as smart buildings.

5. Brunei Darussalam joined in 1984, Viet Nam in 1995, Lao PDR and Myanmar in 1997 and Cambodia in 1999.

CONCLUSION

To become an Asian Tiger, Malaysia will need endogenous research

Malaysia's chances of emulating the success of the 'Asian Tigers' and reaching its goal of becoming a high-income country by 2020 will depend upon how well it succeeds in stimulating the commercialization of technology and innovation. Foreign multinational firms are generally engaged in more sophisticated R&D than national firms. However, even the R&D conducted by foreign firms tends to be confined to product proliferation and problem-solving, rather than pushing back the international technology frontier.

R&D is conducted predominantly in large-scale enterprises in the electronics, automotive and chemical industries, where it mainly involves process and product improvements. SMEs make little contribution to R&D, even though they make up 97% of all private firms.

Even the foreign multinationals which dominate private sector R&D are heavily dependent on their parent and subsidiary firms based outside Malaysia for personnel, owing to the lack of qualified human capital and research universities within Malaysia to call upon.

The weak collaboration between the principal actors of innovation, namely universities, firms and research institutions is another shortcoming of the national innovation system. It will be critical to nurture the research capabilities of universities and their ties with domestic firms, in order to foster innovation and improve the commercialization rate of intellectual property. Although applied research has expanded at Malaysian universities in recent years following a government drive to promote research excellence, this trend has yet to translate into sufficient numbers of patent applications. Similarly, the low absorptive capacity of domestic firms has made technological upgrading difficult. Intermediary organizations will play an important role in bridging this gap by facilitating effective knowledge transfer.

The following measures would help to remedy some of these problems:

- The role of public research organizations would be strengthened by training a greater number of researchers and technicians and ensuring that the Long-term Research Grant Scheme and E-science Fund effectively target the production of industry-related innovation. There is also a need to correct market failures that have stifled the expansion of vocational and technical education in the country.
- Collaboration between public research institutes, universities and industry should be strengthened through long-term plans, including in-depth technology foresight

exercises targeting specific sectors. In this context, there should be an attempt to integrate basic research with commercialization.

- Public research institutes and universities should be encouraged to act as facilitators in improving the local industrial R&D landscape, by providing domestic firms with critical knowledge and know-how through consulting services and other means. The success of the Malaysian Palm Oil Board in transferring know-how and knowledge can serve as a model in this respect.

In addition, in order to overcome shortages in human capital, the government should:

- encourage Malaysians to pursue tertiary education at the world's leading research-based universities, especially those abroad that have a reputation for undertaking frontier R&D, such as in semiconductors at Stanford University (USA) or in molecular biology at the University of Cambridge (UK); one way of doing this is to offer bonded scholarships to students who gain admission to prestigious universities renowned for exposing students to frontier R&D;
- assist national universities in upgrading the qualifications of their academic personnel, so that tenure is given only on the basis of proven participation in world-class research and publications. There is a need for better linkages between universities and industrial firms, in order to make academic research more relevant to the needs of industry;
- promote stronger scientific links between Malaysian universities and proven international experts in key research areas and facilitate two-way 'brain circulation';
- turn science and technology parks into a major launch pad for new innovative start-ups by encouraging universities to set up technology transfer offices and encouraging parks to become the nodes linking universities with industry; this will require evaluating candidate universities and firms seeking incubation facilities prior to granting them space in science and technology parks, as well as regular reviews to assess the progress made by start-up companies.

KEY TARGETS FOR MALAYSIA

- Attain high-income economy status by 2020;
- Raise the GERD/GDP ratio to 2% by 2020;
- Raise the participation rate in higher education from 40% to 50% by 2020;
- Produce 100 000 PhD-holders by 2020;
- Raise the share of science, technology and mathematics students at university level to 60% of the total by 2020;
- Develop 87 international primary and secondary schools by 2020 with a roll of 75 000 pupils;
- Increase the number of international students to 200 000 by 2020 to make Malaysia the world's sixth-largest destination;
- Reduce carbon emissions by 40% by 2020 over 2012 levels;
- Preserve at least 50% of land as primary forest, as compared to 58% in 2010.

REFERENCES

Chandran, V.G.R. (2010) R&D commercialization challenges for developing countries *Special Issue of Asia–Pacific Tech Monitor*, 27(6): 25–30.

Chandran, V.G.R. and C.Y. Wong (2011) Patenting activities by developing countries: the case of Malaysia. *World Patent Information*, 33 (1):51–57.

MASTIC (2012) *National Survey of Innovation 2023*. Malaysian Science and Technology Information Centre: Putrajaya.

Morales, A. (2010) Malaysia Has Little Room for Palm Oil Expansion, Minister Says. *Bloomberg News Online*, 18 November.

MoSTI (2013) *Malaysia: Science Technology and Innovation Indicators Report*. Ministry of Science, Technology and Innovation: Putrajaya.

MoSTI (2009) *Brain Gain Review*. Ministry of Science, Technology and Innovation: Putrajaya.

NSRC (2013) *PRE Performance Evaluation: Unlocking Vast Potentials, Fast-Tracking the Future*. National Science and Research Council: Putrajaya.

OECD (2013) Malaysia: innovation profile. In: *Innovation in Southeast Asia*. Organisation for Economic Co-operation and Development: Paris.

Rasiah, R. (2014) How much of Raymond Vernon's product cycle thesis is still relevant today? Evidence from the integrated circuits industry. Paper submitted to fulfil the Rajawali Fellowship at Harvard University (USA).

Rasiah, R. (2010) Are Electronics Firms in Malaysia Catching Up in the Technology Ladder? *Journal of Asia Pacific Economy*, 15(3): 301–319.

Rasiah, R.; Yap, X.Y. and K. Salih (2015a) *Provincializing Economic Development: Technological Upgrading in the Integrated Circuits Industry in Malaysia.*

Rasiah R.; Yap, X.S. and S. Yap (2015b) Sticky spots on slippery slopes: the development of the integrated circuits industry in emerging East Asia. *Institutions and Economies*, 7(1): 52–79.

Subramoniam, H. and R. Rasiah (forthcoming) University–industry collaboration and technological innovation: sequential mediation of knowledge transfer and barriers in Malaysia. *Asian Journal of Technology Innovation*.

Thiruchelvam, K.; Ng, B.K. and C. Y. Wong (2011) An overview of Malaysia's national innovation system: policies, institutions and performance. In: W. Ellis (ed.) *National Innovation System in Selected Asian Countries.* Chulalongkorn University Press: Bangkok.

UIS (2014) *Higher Education in Asia: Expanding up, Expanding out*. UNESCO Institute for Statistics: Montreal.

WEF (2012) *Global Competitiveness Report*. World Economic Forum: Geneva.

WTO (2014) *International Trade Statistics*. World Trade Organization: Geneva.

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A major challenge for the region will be to draw on its scientific knowledge base to maintain and expand the range of high-tech exports in increasingly competitive global markets.

Tim Turpin, Jing A. Zhang, Bessie M. Burgos and **Wasantha Amaradasa**

A worker harvests fresh produce from a three-storey greenhouse at the Sky Greens vertical farm in Singapore in 2014. As part of a government drive to increase self-reliance in the production of leafy vegetables, Sky Greens has received some research support.
Photo: © Edgar Su/Reuters

27 · Southeast Asia and Oceania

Australia, Cambodia, Cook Islands, Fiji, Indonesia, Kiribati, Lao People's Democratic Republic, Federated States of Micronesia, Malaysia, Myanmar, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, Viet Nam

Tim Turpin, Jing A. Zhang, Bessie M. Burgos and Wasantha Amaradasa

INTRODUCTION

The region has largely withstood the global crisis

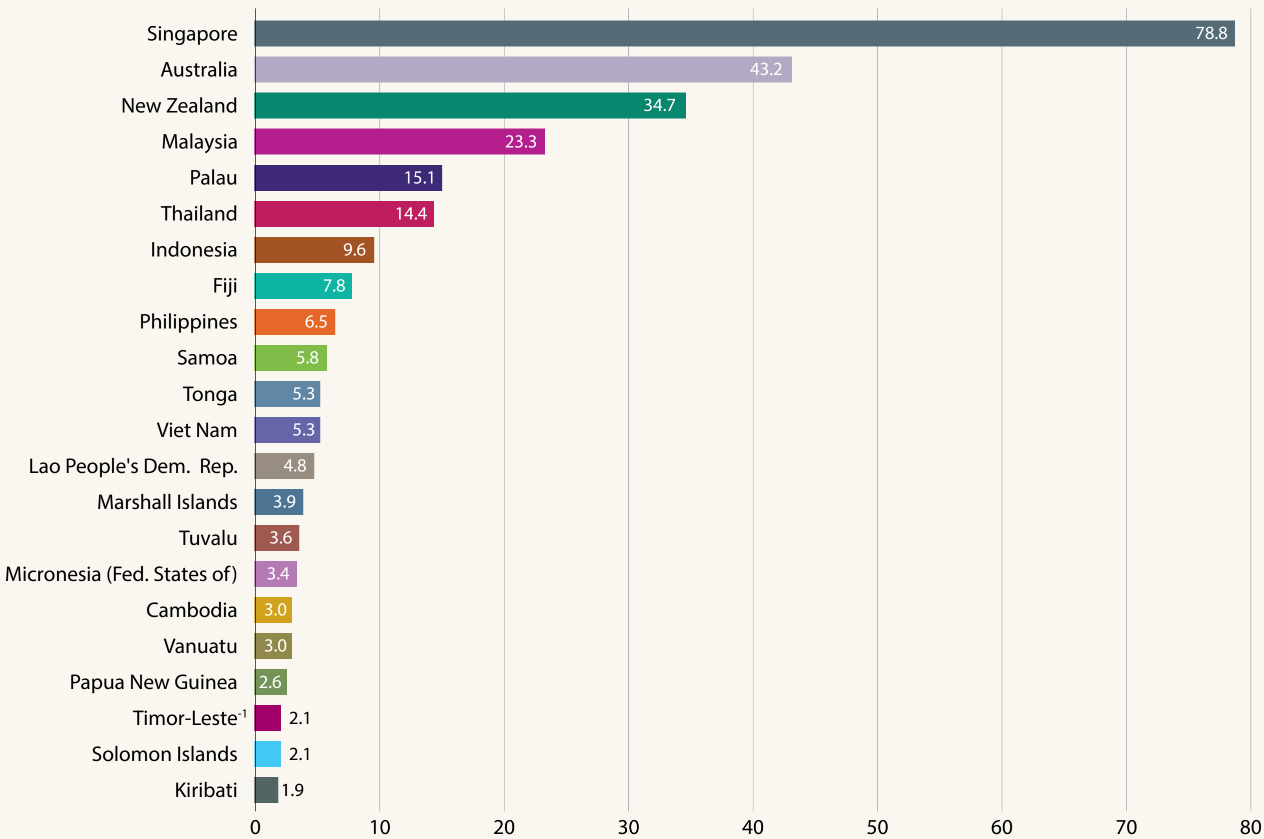
The countries covered by the present chapter[1] together account for over 9% of the world's population. Taken as a group, they produced 6.5% of the world's scientific publications (2013) but only 1.4% of global patents (2012). GDP per capita at current prices ranges from just under PPP$ 2 000 in Kiribati to PPP$ 78 763 in Singapore (Figure 27.1). Australia and Singapore together produce four-fifths of the region's patents and publications.

Economically, the region fared comparatively well through the global financial crisis of 2008–2009. Although growth rates dipped in 2008 or 2009, a number of countries avoided recession altogether, including Australia (Figure 27.2). As a consequence, pressures on budgets for science and technology (S&T) have not been as severe as predicted back in 2010. Timor-Leste even recorded insolent growth rates up until 2012, buoyed by foreign direct investment (FDI) that peaked at 6% of GDP in 2009 before falling back to just over 1.6% in 2012.

According to the World Bank's Knowledge Economy Index, there has been a general slip in overall rankings in Southeast Asia since 2009. New Zealand and Viet Nam are the only ones to have improved their position. Some, such as Fiji, the Philippines and Cambodia, even slipped considerably over this period. Singapore continues to lead the region for the innovation component of the same index and Australia and New Zealand that for education. The Global Innovation Index tends to rank countries in a similar order.

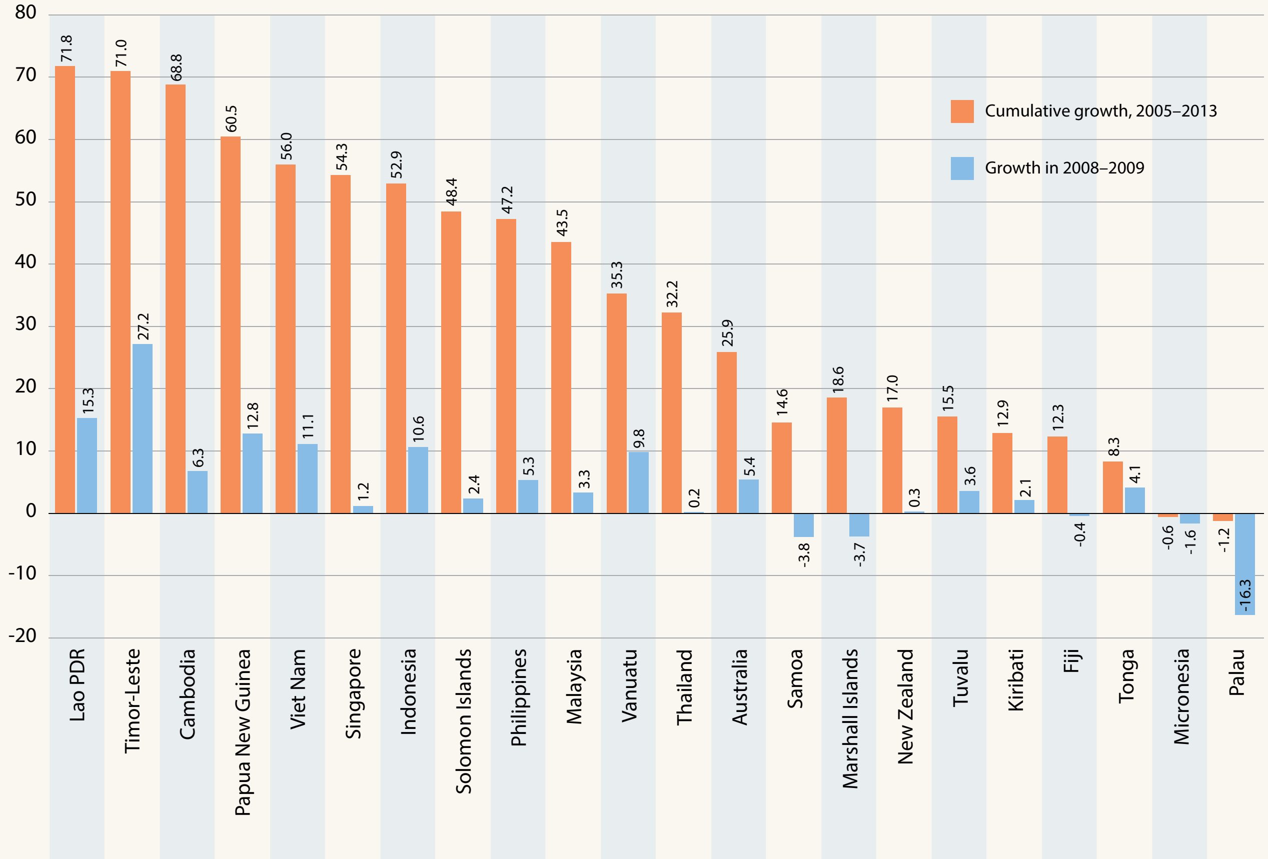
1. Malaysia is covered in greater detail in Chapter 26.

Figure 27.1: **GDP per capita in Southeast Asia and Oceania, 2013**
In thousands of current PPP$



-n = data are for *n* years before reference year
Source: World Bank's World Development Indicators, April 2015

Figure 27.2: **Trends in GDP growth in Southeast Asia and Oceania, 2005–2013**



Note: For Timor-Leste, the most recent data are for 2012, not 2013.
Source: World Bank's World Development Indicators, April 2015

Strong growth in internet access since 2010 has levelled out the disparity between countries to some extent, although connectivity remained extremely low in the Solomon Islands (8%), Cambodia (6%), Papua New Guinea (6.5%), Myanmar (1.2%) and Timor-Leste (1.1%) in 2013 (Figure 27.3). Advances in mobile phone technology have clearly been a factor in the provision of internet access to remote areas. The flow of knowledge and information through internet is likely to play an important role in the more effective dissemination and application of knowledge across the vast Pacific Island nations and least developed countries of Southeast Asia.

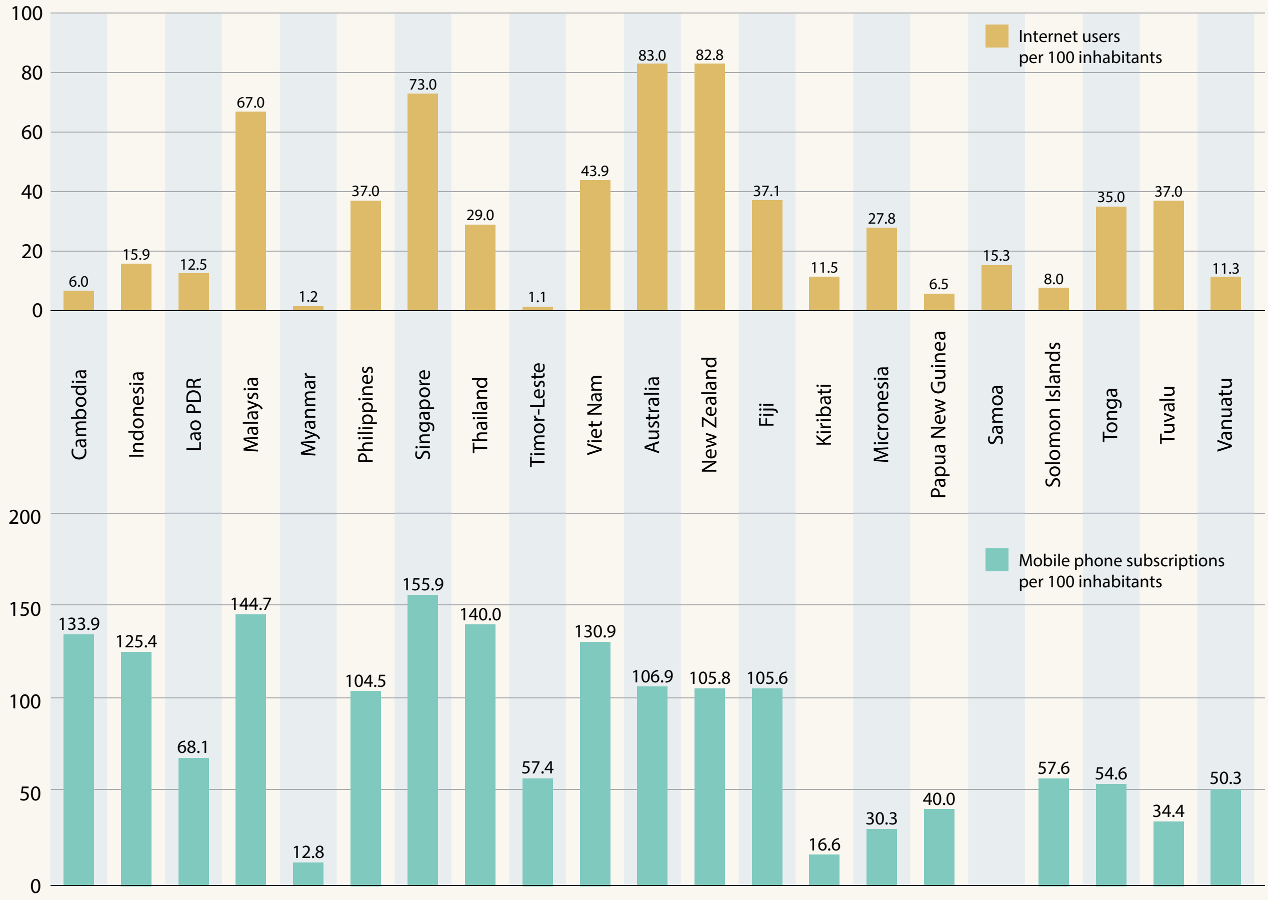
Political change at national and regional levels

Thailand has been experiencing political instability for the past five years, culminating in a military coup in 2014 and erratic economic growth. Indonesia, by contrast, has enjoyed a period of comparative stability with economic growth of about 4% on average since 2010; the government elected in 2014 has introduced a number of fiscal and structural reforms designed to encourage investment (World Bank, 2014). These reforms should help accelerate business R&D, which was already showing solid growth in 2010.

Myanmar has been undergoing a period of democratic reform since 2011, which has prompted the easing of international sanctions. The return of US and European Union (EU) trade privileges has already generated significant investment growth across many sectors. A foreign investment law passed in 2012, followed in January 2014 by a Special Economic Zone Law, provides incentives for export-oriented industries. Myanmar's geostrategic location between India and China, coupled with the creation of the Association of Southeast Asian Nations (ASEAN) Economic Community in 2015, has led the Asian Development Bank to predict an 8% growth rate per year for Myanmar through the next decade.

Australia's incoming government in September 2013 coincided with a steep decline in the value of its natural resources, as demand for minerals eased in China and elsewhere. As a consequence, the new government sought to reduce public spending, in order to balance its 2014–2015 budget. Science and technology were among the many casualties of this cost-cutting exercise. On 17 June 2015, Australia signed a free trade agreement with China which removes almost all import duties. 'It is the highest degree

Figure 27.3: **Internet and mobile phone access in Southeast Asia and Oceania, 2013 (%)**



Source: International Telecommunications Union

of liberalization of all the free trade agreements China has so far signed with any economy', commented China's commerce minister Gao Hucheng at the signing (Hurst, 2015).

A common market by the end of the year

The ASEAN countries intend to transform their region into a common market and production base with the creation of the ASEAN Economic Community by the end of 2015. The planned removal of restrictions to the cross-border movement of people and services is expected to spur co-operation in science and technology. Moreover, the increased mobility of skilled personnel within the region should be a boon for the development of skills, job placement and research capabilities within ASEAN member states and enhance the role of the ASEAN University Network (Sugiyarto and Agunias, 2014). As part of the negotiating process, each member state may express its preference for a specific research focus. The Laotian government, for instance, hopes to prioritize agriculture and renewable energy. More contentious are proposals to develop hydropower on the Mekong River, given the drawbacks of this energy option (Pearse-Smith, 2012).

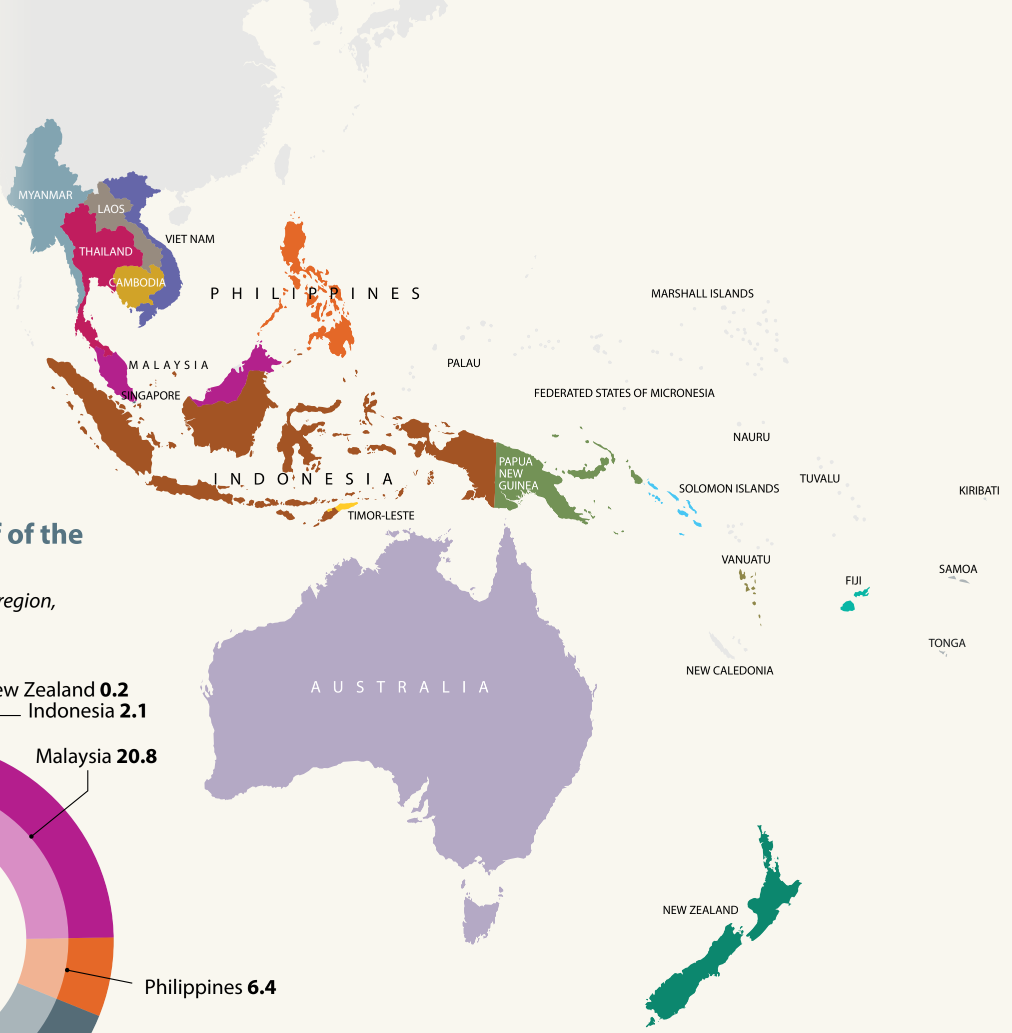
TRENDS IN STI GOVERNANCE

High-tech exports have defied predictions

In spite of pessimistic predictions, high-tech exports across the region have performed well since 2008. Overall, high-tech exports from all countries in the region increased by 28%. However, the situation has not been uniform. Between 2008 and 2013, almost all countries increased the value of their exports. For Malaysia and Viet Nam, the increase was significant: high-tech exports from Viet Nam increased almost tenfold. The Philippines, by contrast, recorded a reduction of nearly 27% over the same period.

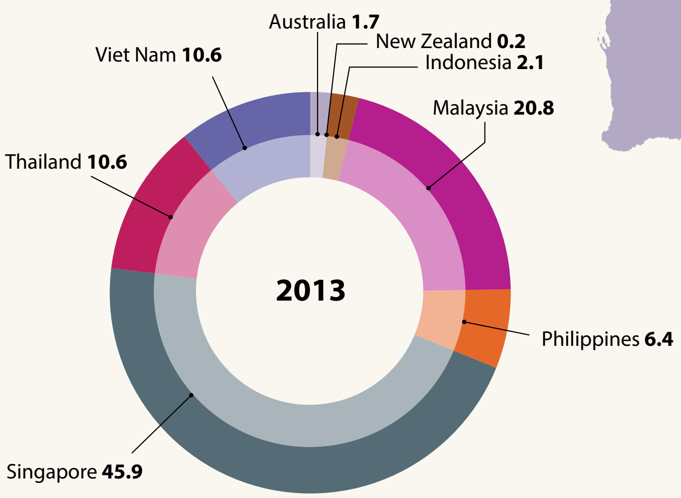
Four countries dominate the export of high-tech products from the region. Singapore accounts for nearly 46% and Malaysia just under 21% (Figure 27.4). Malaysia, Singapore, Thailand and Viet Nam together account for 90% of high-tech exports from the region. Two product categories dominate these exports: computers/office machines (19.3%) and, above all, electronic communications: (67.1%). It is likely that these export products included a considerable proportion of re-exported components, so these data should be interpreted accordingly. Although Singapore and Malaysia record a

Figure 27.4:
Trends in high-tech exports from Southeast Asia and Oceania, 2008 and 2013



Singapore exports almost half of the region's high tech goods

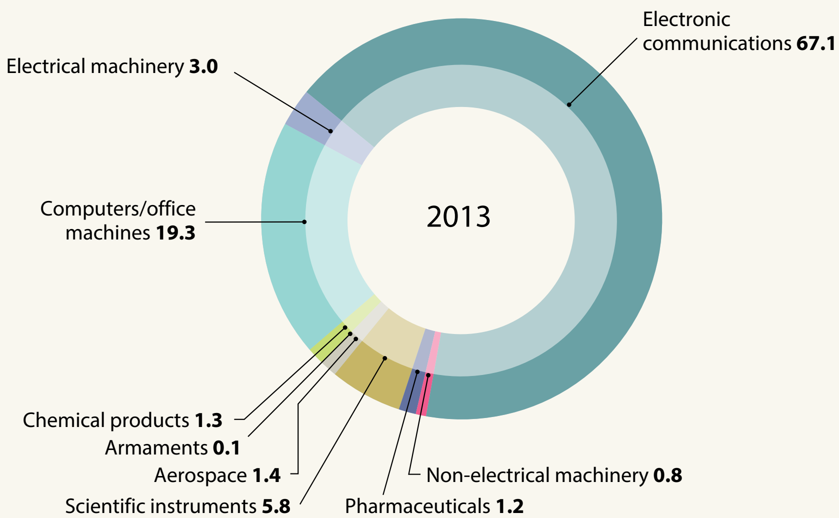
National shares of high-tech exports from the region, 2013 (%)



Note: The regional shares of Cambodia, Fiji, Kiribati, Myanmar, Palau, Papua New Guinea, Samoa, the Solomon Isalnds, Timor-Leste, Tonga and Vanuatu are close to zero.

Share of electronic communications in the region's high-tech exports (%)

Total exports from the region by type, 2013



45.9%

Singapore's share of the region's high-tech exports in 2013

20.8%

Malaysia's share of the region's high-tech exports in 2013

10.6%

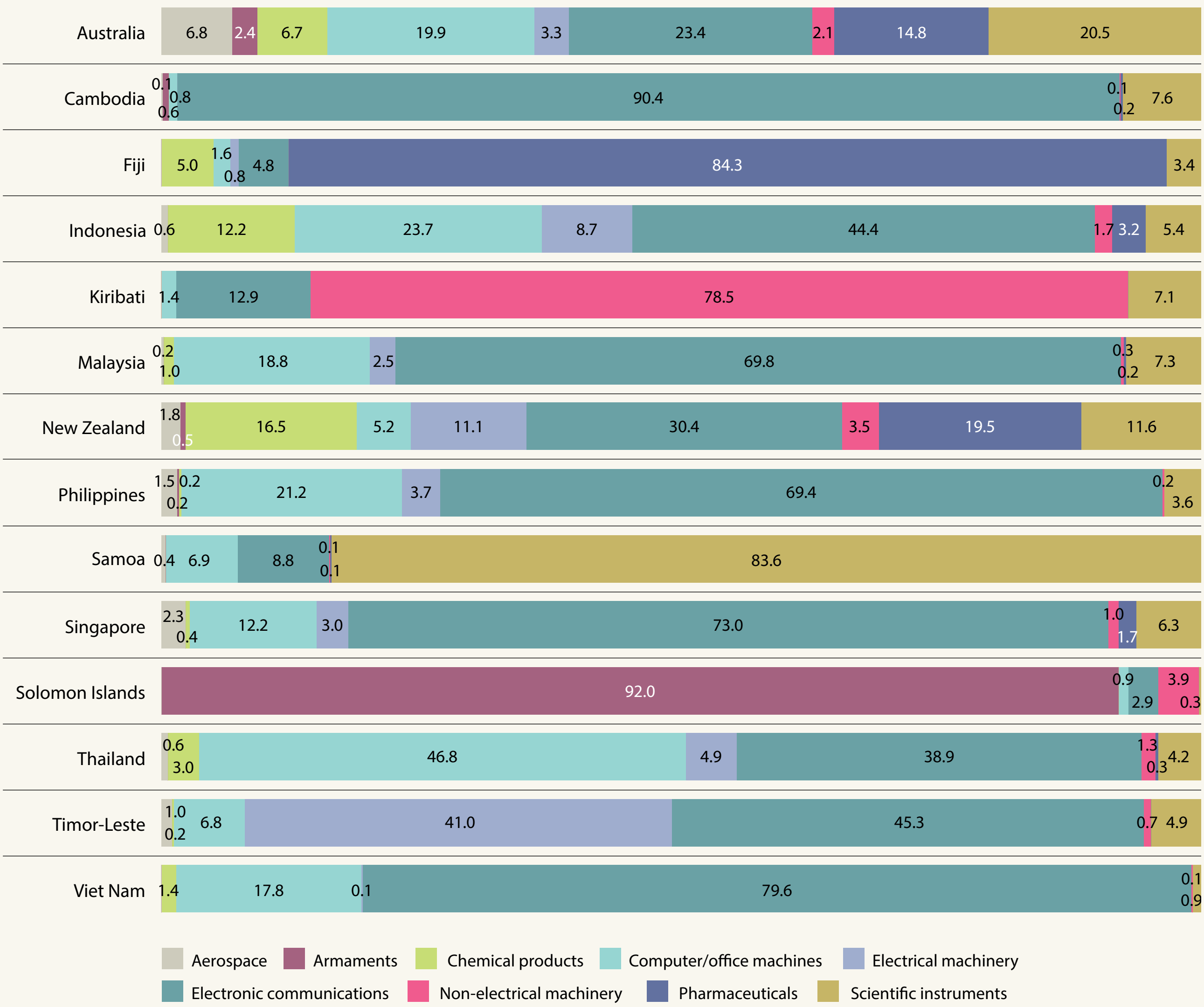
Respective shares of Thailand and Viet Nam in the region's high-tech exports in 2013

1.7%

Australia's share of the region's high-tech exports in 2013

Electronic communications dominate high-tech exports

National high-tech exports by type, 2013 (%)



Growth in high-tech exports has been fastest in Cambodia and Viet Nam, exports have receded in the Philippines and Fiji

US$ millions

	High-tech exports (US$ millions)		Change (US$ millions)	Change (%)
	2008	2013		
Australia	4 340.3	5 193.2	852.9	19.7
Cambodia	3.8	76.5	72.7	1 913.6
Fiji	5.0	2.7	-2.3	-45.7
Indonesia	5 851.7	6 390.3	538.6	9.2
Malaysia	43 156.7	63 778.6	20 622.0	47.8
New Zealand	624.3	759.2	134.9	21.6
Philippines	26 910.2	19 711.4	-7 198.8	-26.8
Samoa	0.3	0.2	-0.1	-40.6
Singapore	123 070.8	140 790.8	17 719.9	14.4
Thailand	33 257.9	37 286.4	4 028.5	12.1
Viet Nam	2 960.6	32 489.1	29 528.5	997.4
Total	240 181.9	306 482.5	66 300.7	27.6

Source: United Nations' Comtrade database comparatively high proportion of business sector R&D, it is likely that much of the research associated with computers/ office machines and electronic communications could be undertaken globally, rather than locally. Both countries host numerous large multinational companies. Australia also has a high proportion of business sector funding but, in Australia's case, this is largely a product of R&D undertaken in, and on behalf of, the mining and minerals sector.

Although scientific output has increased in global terms, there has been no overall rise in the level of patenting across the region. The region has even receded for this metric: Southeast Asia and Oceania produced 1.4% of the world's patents in 2012, compared to 1.6% in 2010, largely owing to the drop in patents registered from Australia. Four countries accounted for 95% of the patents obtained by the region: Australia, Singapore, Malaysia and New Zealand. The significant rise in high-tech exports across some countries in the region is at odds with the comparatively small global proportion of patenting activity. A major challenge for the region will be to draw on its scientific knowledge base to maintain and expand the range of high-tech exports in increasingly competitive global markets.

Squaring science policy with sustainable development still a challenge

A tension between the competing objectives of scientific excellence and scientific practice characterizes much of the region. In most countries, there is a clear desire to link S&T policies to innovation and development strategies. In the industrialized economies of Australia, New Zealand and Singapore, investment in science is viewed, in policy terms, as a component of national innovation strategies. Making science subservient to economic objectives at the policy level nevertheless carries a danger of underserving the many ways in which science can underpin socio-economic and cultural development, such as in health, education or in addressing global sustainability challenges.

Among developing economies, science policy is generally linked to development strategies yet, in this context too, there is a tension between assessments of scientific capacity through measures such as citation and development priorities. Among the poorer countries such as Cambodia, Lao PDR and Timor-Leste, or transition economies such as Myanmar, the development imperative is evident in recent policy documents which focus on harnessing human capital to serve basic development needs. International projects can be a way of reconciling limited national means with sustainable development goals. For instance, the Asian Development Bank funded a project to develop the use of biomass in three of the six countries located[2] in the Greater Mekong Subregion between 2011 and 2014: Cambodia, Lao People's Democratic Republic (PDR) and Viet Nam.

2. the other three being China, Myanmar and Thailand

Many of the less economically developed countries are struggling to steer their own scientific efforts toward sustainable development, at a time when the United Nations' Sustainable Development Goals are about to take over from the Millennium Development Goals in late 2015. They could begin by encouraging their scientists to focus more on attaining local goals for sustainable development, rather than on publishing in high-profile international journals on topics that may be of lesser local relevance. The difficulty with this course of action is that the key metrics for recognizing scientific quality are publications and citation data. The answer to this dilemma most likely lies in the need to recognize the global nature of many local development problems. As pointed out by Perkins (2012):

> We are dealing with problems without boundaries and we underestimate the scale and nature of their consequences at our collective peril. As global citizens, the research and policy communities have an obligation to collaborate and deliver, so arguing for national priorities seems irrelevant.

TRENDS IN R&D

Developing research personnel high on the agenda

Across the region, human resources for S&T are primarily concentrated in Australia, Malaysia, Singapore and Thailand. The strongest concentration of researchers is to be found in Singapore, which, with 6 438 full-time equivalent (FTE) researchers per million inhabitants in 2012, is well ahead of all G7 countries (Table 27.1). Technicians across the region are most concentrated in Australia and New Zealand, reflecting a pattern found in other mature economies, but Singapore has a much lower concentration. One of the driving forces for the freer flow of skills across ASEAN member States has been the demand from Malaysia and Singapore for ready access to technical personnel from elsewhere in the region. Malaysia and Thailand are both suppliers and recruiters of skilled personnel, as are the Philippines in some specialist fields. The freer flow of skilled personnel across ASEAN after 2015 should benefit both supplier and recruiter nations.

In terms of research training, Malaysia and Singapore stand out for their significant investment in tertiary education. Over the past decade, the share of their education budget devoted to tertiary education has risen from 20% to over 35% in Singapore and 37% in Malaysia (Figure 27.5). These two countries also happen to have the greatest share of PhD candidates among university students. In most countries, new institutions have sprung up to accommodate the growing demand for higher education.

Table 27.1: **Research personnel in Southeast Asia and Oceania, 2012 or closest year**

	Population ('000s)	Total researchers (FTE)	Researchers per million inhabitants (FTE)	Technicians per million inhabitants (FTE)
Australia (2008)	21 645	92 649	4 280	1 120
Indonesia (2009)	237 487	21 349	90	–
Malaysia (2012)	29 240	52 052	1 780	162
New Zealand (2011)	4 414	16 300	3 693	1 020
Philippines (2007)	88 876	6 957	78	11
Singapore (2012)	5 303	34 141	6 438	462
Thailand (2011)	66 576	36 360	546	170

Source: UNESCO Institute for Statistics, June 2015

There is also a growing pattern of subregional university collaboration. The ASEAN University Network established in the late 1990s now consists of 30 universities across the ten ASEAN countries. It has served as a model for more recent spin-offs, such as the Pacific Island Network constituted in 2011, which consists of ten Pacific universities operating across five countries. In parallel, many Australian and New Zealand universities have established campuses at universities across the region.

Four countries have a high proportion of tertiary students enrolled in science degrees: Myanmar (23%), New Zealand and Singapore (each with 14%) and Malaysia (13%). Myanmar also has the highest proportion of women enrolled in tertiary education, in general. It will be interesting to see if Myanmar manages to maintain this high proportion of women among students as it pursues its transition.

Women constitute half of researchers in Malaysia, the Philippines and Thailand but remain an unknown quantity in Australia and New Zealand, for which there are no recent data (Figure 27.6). More than half of researchers are employed by the higher education sector in most countries (Figure 27.7). Academics even make up eight out of ten researchers in Malaysia, suggesting that the multinational companies on its soil either do not count a majority of Malaysians on their research staff or do not conduct in-house R&D. The notable exception is Singapore, where half of researchers are employed by industry, compared to between 30% and 39% elsewhere in the region. In Indonesia and Viet Nam, the government is a major employer of researchers.

Better R&D data as vital as greater investment

Although data on gross domestic expenditure on R&D (GERD) are rather sketchy and date back several years in many cases – or are even non-existent for the smallest Pacific Island states – they still illustrate the blend of scientific capacity across Southeast Asia and Oceania. Singapore has conceded its regional lead for R&D intensity, which shrank from 2.3%
to 2.0% of GDP between 2007 and 2012, having been overtaken by Australia, which has maintained a steady investment level of 2.3% of GDP in R&D (Table 27.2). Australia's dominant position may be short-lived, however, as Singapore plans to increase its GERD/GDP ratio to 3.5% by 2015.

A comparatively high share of R&D is performed by the business sector in four countries: Singapore, Australia, the Philippines and Malaysia (see Chapter 26). In the case of the latter two, this is most likely a product of the strong presence of multinational companies in these countries. Since 2008, many countries have boosted their R&D effort, including in the business enterprise sector. However, in some cases, business expenditure on R&D is highly concentrated in the natural resource sector, such as mining and minerals in Australia. The challenge for many countries will be to deepen and diversify business sector involvement across a wider range of industrial sectors.

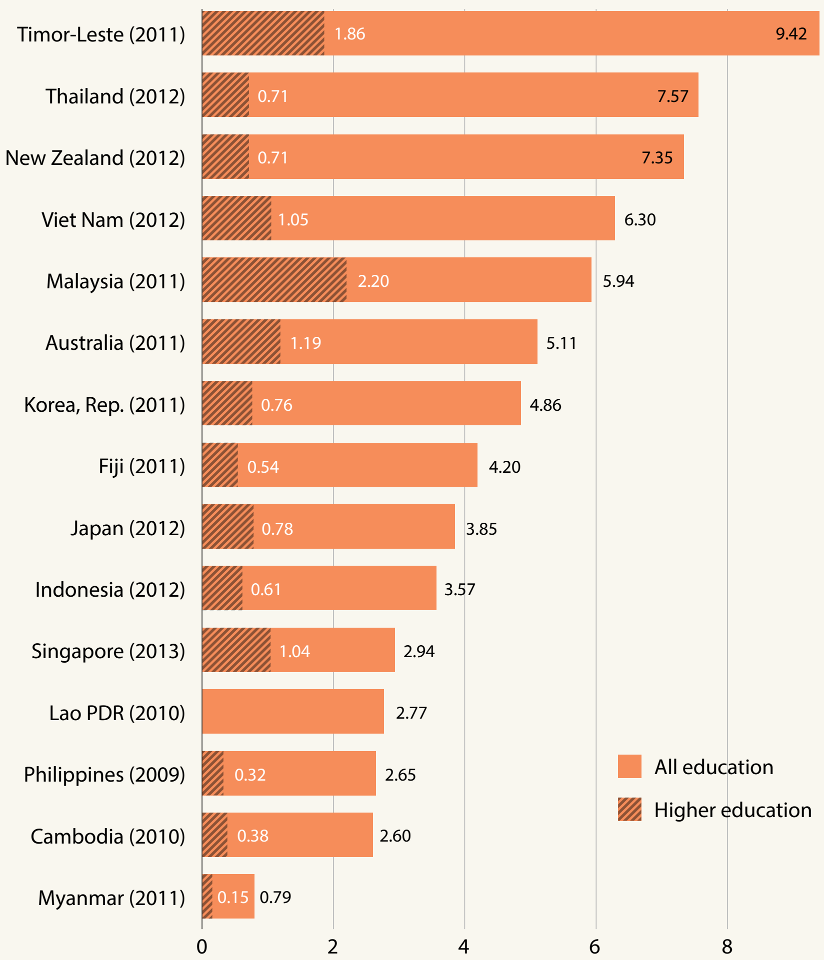
An emerging Asia–Pacific knowledge hub

The number of scientific publications catalogued in the Web of Science by the countries under study showed healthy growth between 2005 and 2014, some Asian countries even recording annual growth of 30% or more (Figure 27.8). Fiji and Papua New Guinea were the main contributors to publications from the Pacific Island states. Whereas Australia and New Zealand publish more in life sciences, the Pacific Islands tend to focus on geosciences. Southeast Asian countries specialize in both.

Figure 27.5: **Trends in higher education in Southeast Asia and Oceania, 2013 or closest year**

Five countries devote more than 1% of GDP to higher education

As a share of GDP, 2013 (%)



2.20%

Share of GDP devoted to higher education by Malaysia in 2011

0.15%

Share of GDP devoted to higher education by Myanmar in 2011

19.9%

Average share of spending on higher education in Southeast Asia and Oceania within education expenditure (%)

3.3%

Average share of the population enrolled in higher education in Southeast Asia and Oceania (among countries listed in the table below)

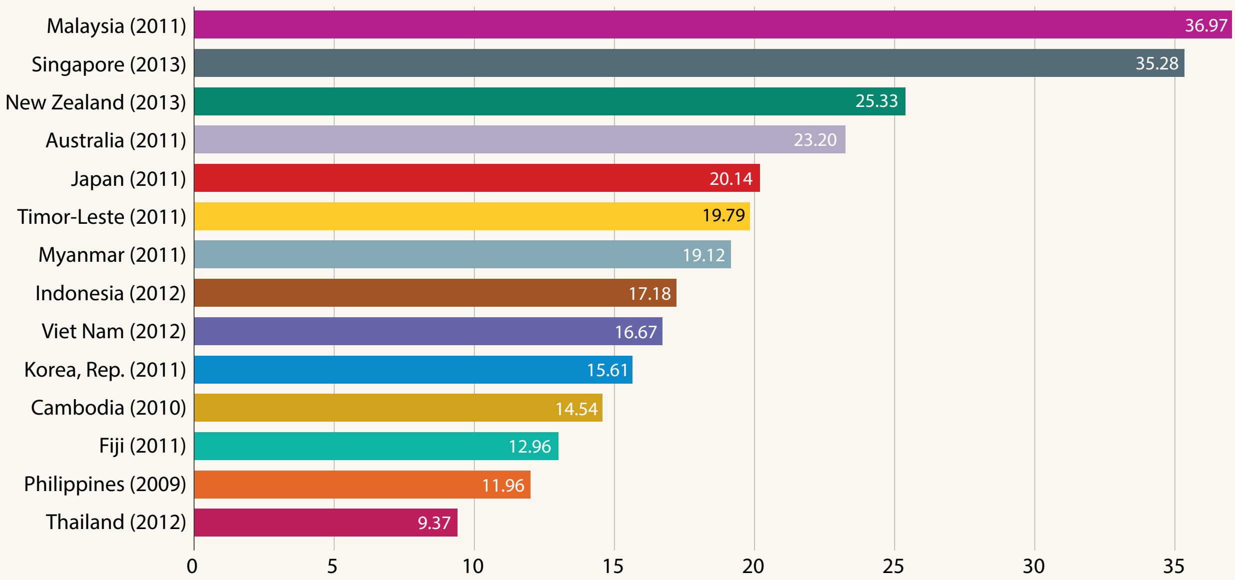
Australia and New Zealand count the greatest share of tertiary students among the total population

	Year	Tertiary enrolment, all fields	Share of total pop. (%).	Tertiary enrolment in scientific disciplines	Share of science in tertiary enrolment (%)
Australia	2012	1 364 203	5.9	122 085	8.9
New Zealand	2012	259 588	5.8	36 960	14.2
Singapore	2013	255 348	4.7	36 069	14.1
Malaysia	2012	1 076 675	3.7	139 064	12.9
Thailand	2013	2 405 109	3.6	205 897	8.2[-2]
Philippines	2009	2 625 385	2.9	–	–
Indonesia	2012	6 233 984	2.5	433 473[-1]	8.1
Viet Nam	2013	2 250 030	2.5	–	–
Lao PDR	2013	137 092	2.0	6 804[-1]	5.4[-1]
Cambodia	2011	223 222	1.5	–	–
Myanmar	2012	634 306	1.2	148 461	23.4

-*n* = data are for *n* years before reference year

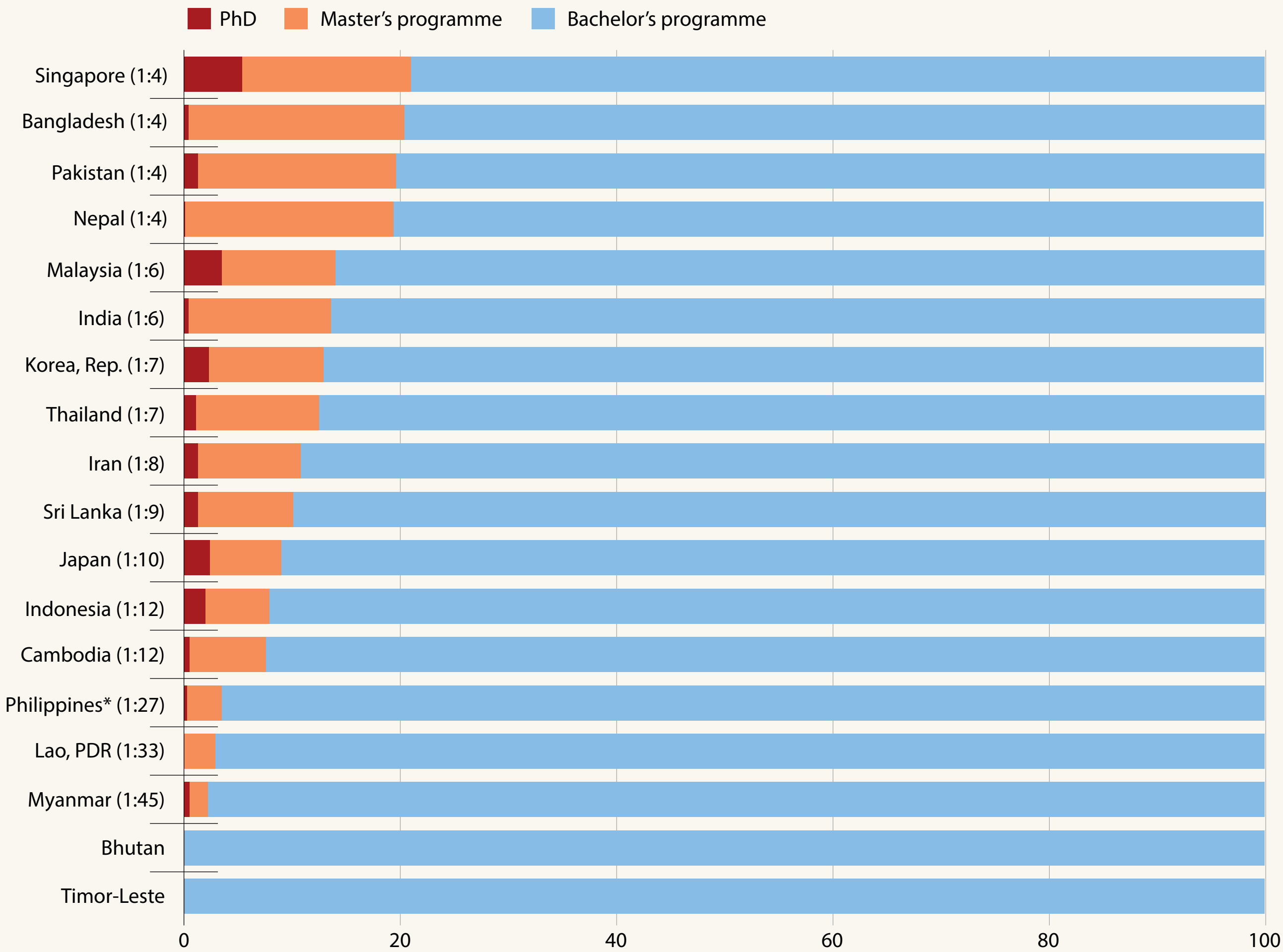
More than one-third of education spending goes on higher education in Malaysia and Singapore

As a share of total public expenditure on education, 2013 or nearest year (%)



Singapore and Malaysia have the greatest share of PhD students among university students

University enrolment in Asia by level of study, 2011, selected countries



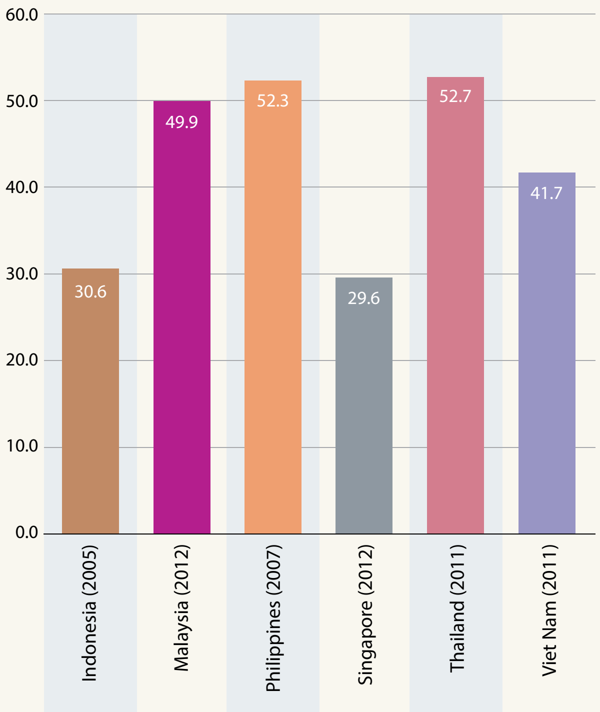
* Data for the Philippines are for 2008.

Note: Between brackets is the ratio of enrolment in master's/PhD programmes to bachelor's programmes.

Source: UNESCO Institute for Statistics, June 2015; for university enrolment in Asia: UIS (2014)

Figure 27.6: **Women researchers (HC) in Southeast Asia, 2012 or closest year (%)**

Head counts



Source: UNESCO Institute for Statistics, June 2015

Countries around the Pacific Rim are seeking ways to link their national knowledge base to regional and global advances in science. One motivation for this greater interconnectedness is the region's vulnerability to geohazards such as earthquakes and tsunamis – the Pacific Rim is not known as the Ring of Fire for nothing. The need for greater disaster resilience is inciting countries to develop collaboration in the geosciences. Climate change is a parallel concern, as the Pacific Rim is also one of the most vulnerable regions to rising sea levels and increasingly capricious weather patterns. In March 2015, much of Vanuatu was flattened by Cyclone Pam. Partly to ensure the viability of its agriculture, Cambodia has adopted a *Climate Change Strategic Plan* covering 2014 –2023, with financial support from the European Union and others.

The citation rate for papers published across the region is growing. Between 2008 and 2012, countries from Southeast Asia and Oceania surpassed the OECD average for the number of papers among the 10% most-cited. In some cases, the growth in international co-authorship may be a factor in this positive outcome, as in Cambodia. All but Viet Nam and Thailand have increased their share of internationally co-authored scientific papers over the past decade. For the smaller or transition economies, international collaboration even represents more than 90% of the total, as in Papua New Guinea, Cambodia, Myanmar and some Pacific Island states.

Although collaboration is strongly linked to global knowledge hubs such as the USA, UK, China, India, Japan and France, there is evidence of an emerging Asia–Pacific 'knowledge hub.' Australia, for instance, is one of the top five collaborators for 17 of the 20 countries in Figure 27.8.

The Asia–Pacific Economic Cooperation (APEC) intends to accompany the development of an Asia–Pacific knowledge hub. APEC completed a study[3] in 2014 of skills shortages in the region, with a view to setting up a monitoring system to address training needs before these shortages become critical.

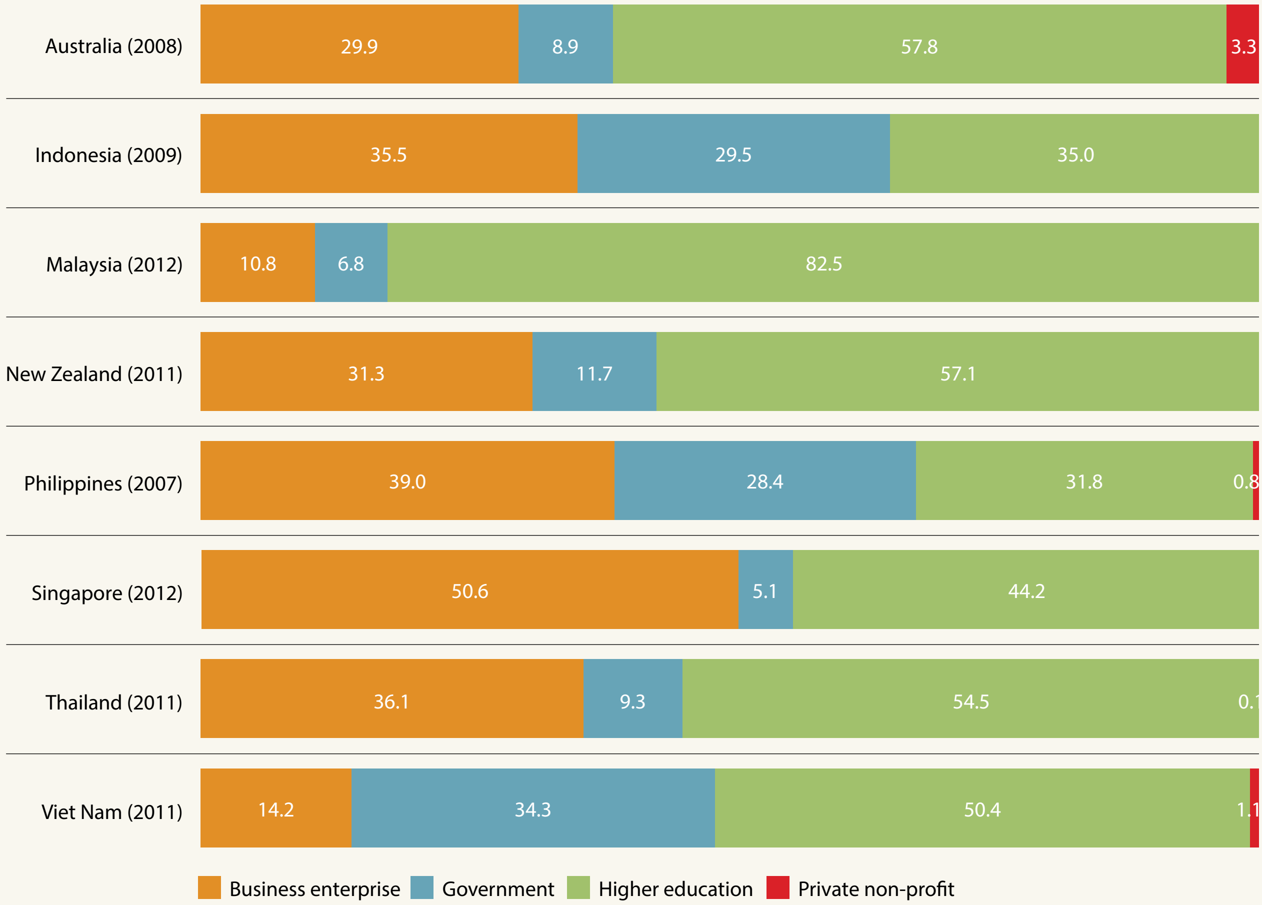
The ASEAN Committee on Science and Technology launched the ASEAN Krabi initiative in 2010, which has since developed the *ASEAN Plan of Action on Science, Technology and Innovation* (APASTI) covering the period 2016–2020. The interesting feature of APASTI is its integrated approach to science, technology and innovation (STI); it seeks to raise competitiveness across the region by contributing to both social inclusion and sustainable development. APASTI is scheduled to be adopted by ASEAN member states by the end of 2015; it identifies eight thematic areas:

- Focusing on global markets;
- Digital communication and social media;
- Green technology;
- Energy;
- Water resources;
- Biodiversity;
- Science; and
- 'Innovation for life'.

In parallel, schemes such as the annual ASEAN–European Union Science, Technology and Innovation Days are reinforcing dialogue and co-operation between these two regional bodies. The second of these days took place in France in March 2015 and the third is scheduled to take place in Viet Nam in 2016. In 2015, the theme was Excellent Science in ASEAN. Some 24 exhibitors presented research from their institution or enterprise. There were also sessions on scientific topics and two policy sessions, one on the evolution of the ASEAN Economic Community and the second on the importance of intellectual property rights for the Pacific region. This annual forum was launched within the Southeast Asia–EU Network for Biregional Co-operation project (SEA–EU NET II) funded by the EU's Seventh Framework Programme for Research and Innovation. A network to foster policy dialogue between the EU and the Pacific region has been launched within the same framework programme (see p. 725).

3. See: http://hrd.apec.org/index.php/APEC_Skills_Mapping_Project

Figure 27.7: **Researchers (FTE) in Southeast Asia and Oceania by sector of employment, 2012 or closest year (%)**



Note: The data for Viet Nam are by head count.

Source: UNESCO Institute for Statistics, June 2015

Table 27.2: **GERD in Southeast Asia and Oceania, 2013 or closest year**

	As % of GDP	Per capita PPP$	Share performed by business (%)	Share funded by business (%)
Australia (2011)	2.25	921.5	57.9	61.9^{-3}
New Zealand (2009)	1.27	400.2	45.4	40.0
Indonesia (2013*)	0.09	6.2	25.7	–
Malaysia (2011)	1.13	251.4	64.4	60.2
Philippines (2007)	0.11	5.4	56.9	62.0
Singapore (2012)	2.02	1 537.3	60.9	53.4
Thailand (2011)	0.39	49.6	50.6	51.7
Viet Nam (2011)	0.19	8.8	26.0	28.4

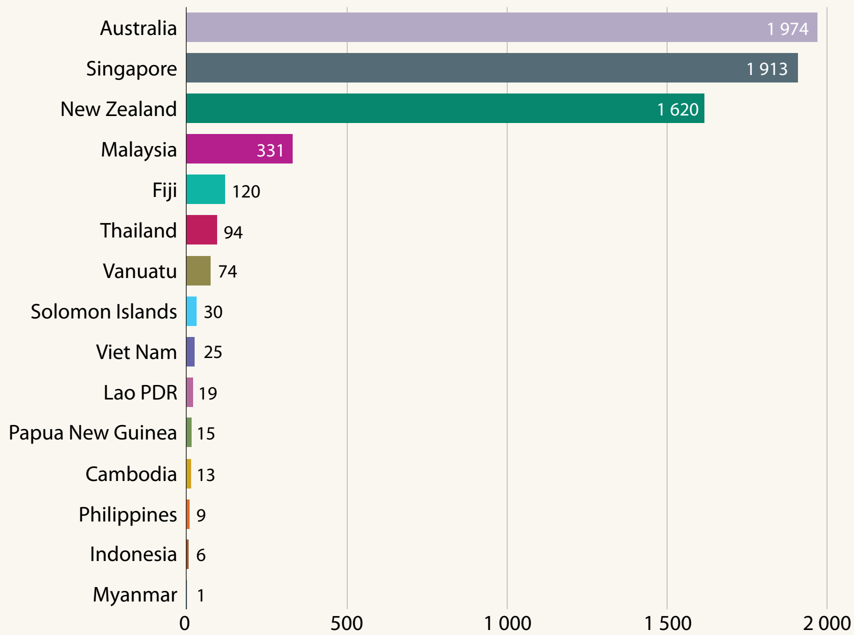
* national estimate

Source: UNESCO Institute for Statistics, June 2015

Figure 27.8: **Scientific publication trends in Southeast Asia and Oceania, 2005–2014**

Scientists from Australia, Singapore and New Zealand are the most prolific

Publications per million inhabitants in 2014



60.1%

Malaysia's annual growth rate for the number of publications, 2005–2014

31.2%

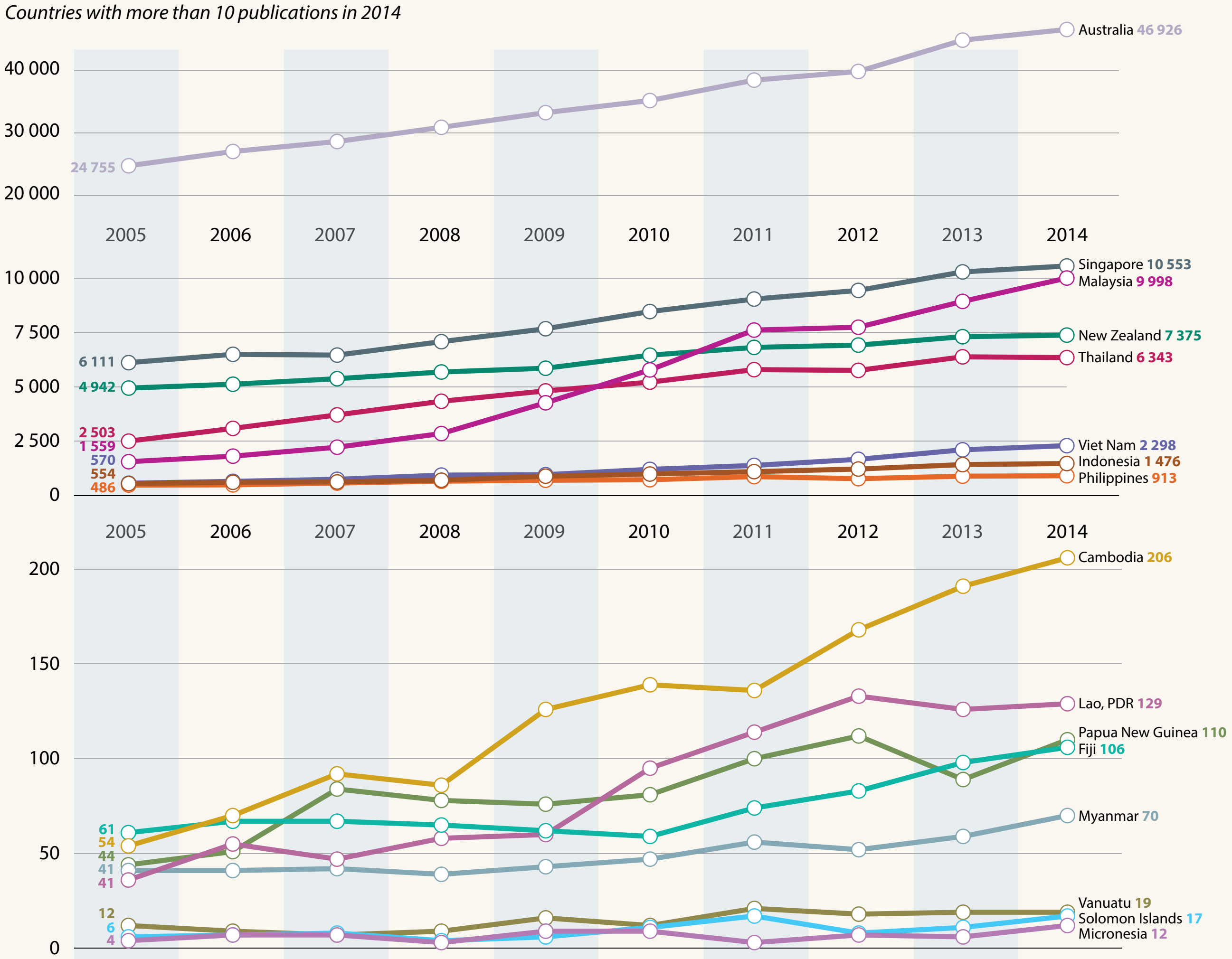
Average annual growth in publications from Viet Nam, Cambodia and Lao PDR, 2005–2014

7.8%

Average annual growth in publications from Australia, New Zealand and Singapore, 2005–2014

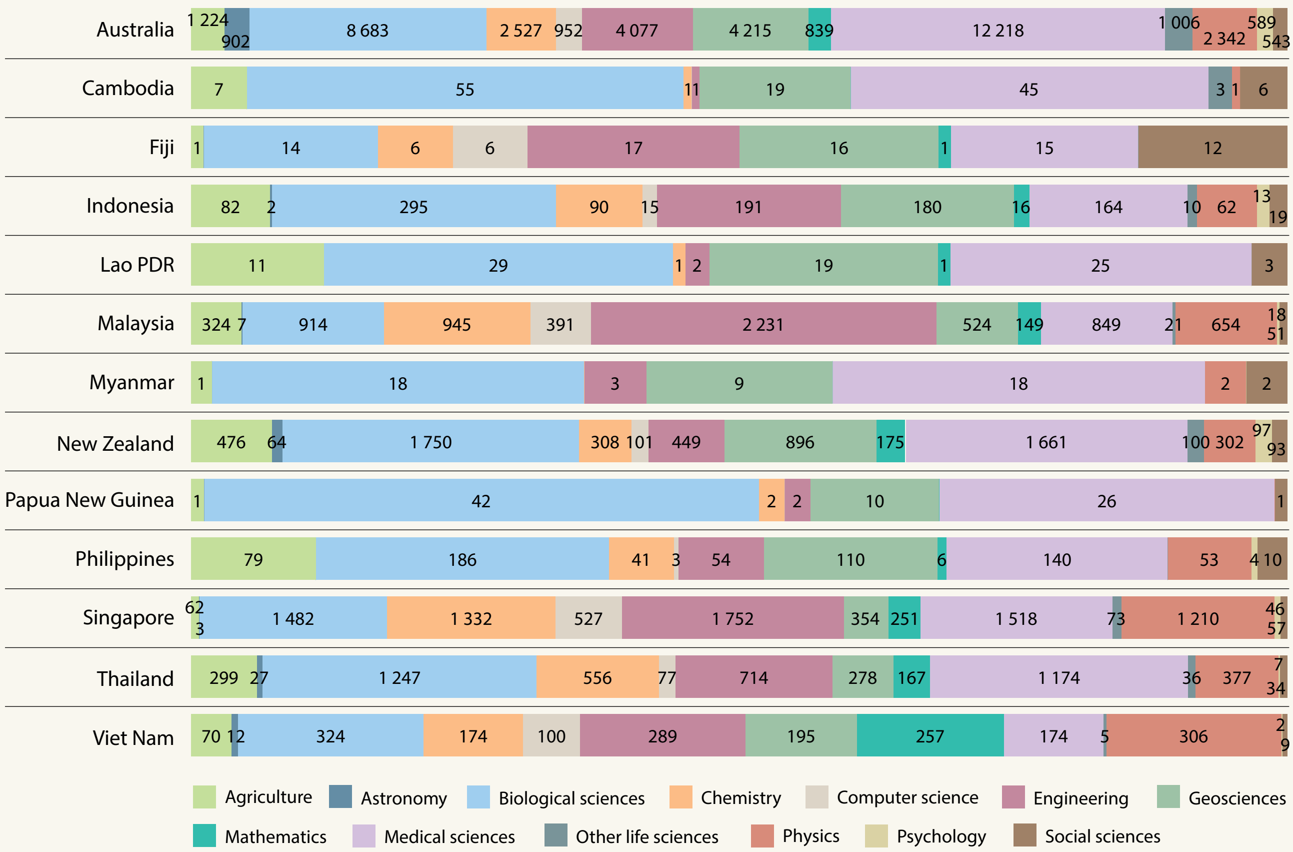
Steady growth in the most prolific countries

Countries with more than 10 publications in 2014



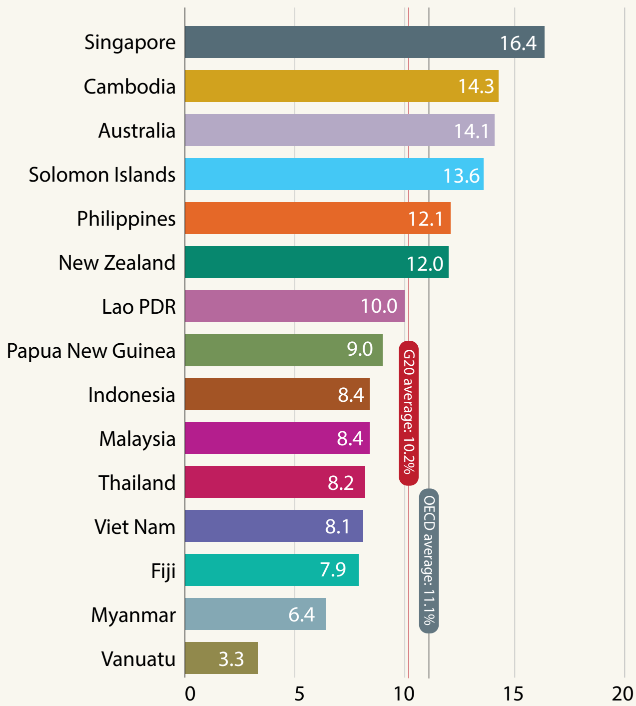
Engineering dominates in Malaysia and Singapore, life sciences and geosciences elsewhere

Countries with more than 20 publications in 2014; cumulative totals by field, 2008–2014



Note: Unclassified articles are excluded.

Six countries topped the OECD average for the share of papers among the 10% most cited between 2008 and 2012



Five countries topped the OECD average for the average citation rate between 2008 and 2012

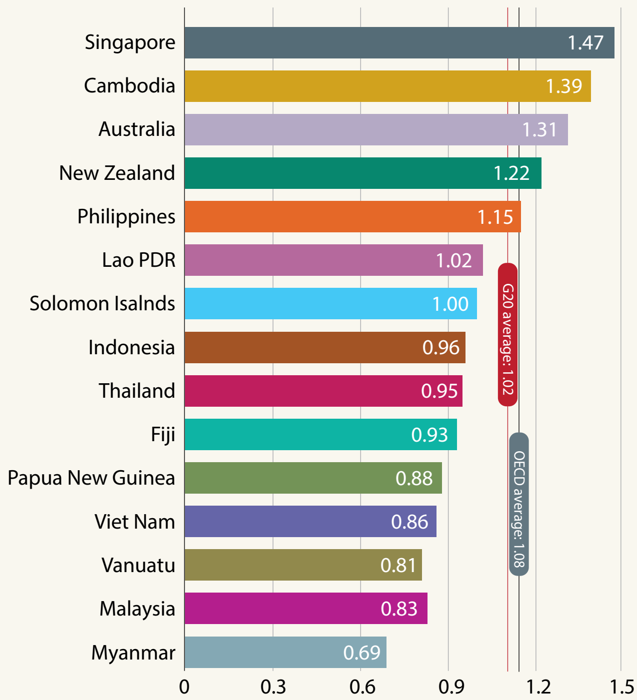


Figure 27.8 *(continued)*

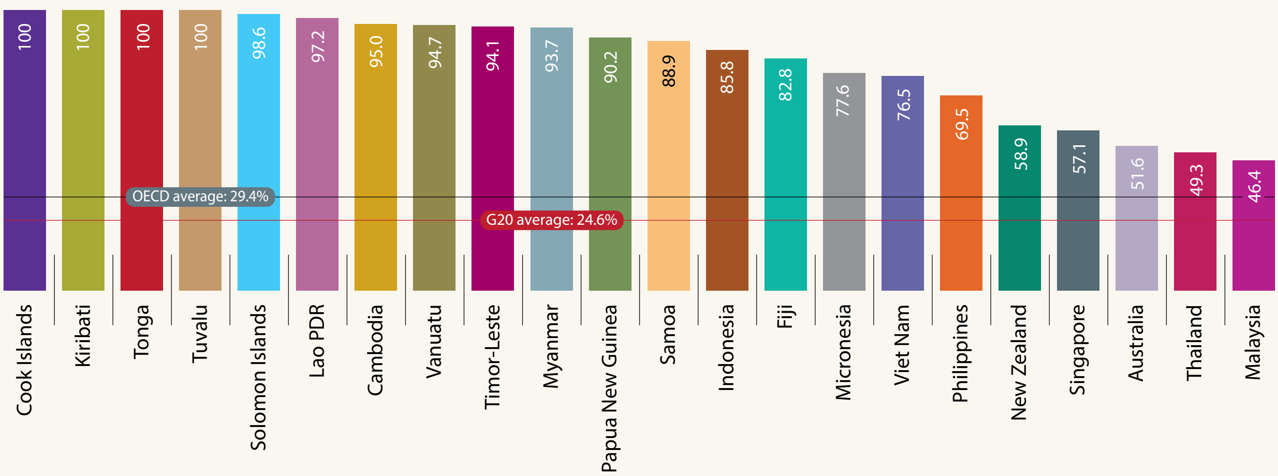
Countries collaborate with a wide range of partners

Main foreign partners, 2008 –2014 (number of papers)

	1st collaborator	2nd collaborator	3rd collaborator	4th collaborator	5th collaborator
Australia	USA (43 225)	UK (29 324)	China (21 058)	Germany (15 493)	Canada (12 964)
Cambodia	USA (307)	Thailand (233)	France (230)	UK (188)	Japan (136)
Cook Islands	USA (17)	Australia/ New Zealand (11)		France (4)	Brazil/Japan (3)
Fiji	Australia (229)	USA (110)	New Zealand (94)	UK (81)	India (66)
Indonesia	Japan (1 848)	USA (1 147)	Australia (1 098)	Malaysia (950)	Netherlands (801)
Kiribati	Australia (7)	New Zealand (6)	USA/Fiji (5)		Papua New Guinea (4)
Lao PDR	Thailand (191)	UK (161)	USA (136)	France (125)	Australia (117)
Malaysia	UK (3 076)	India (2 611)	Australia (2 425)	Iran (2 402)	USA (2 308)
Micronesia	USA (26)	Australia (9)	Fiji (8)	Marshall Islands (6)	New Zealand/ Palau (5)
Myanmar	Japan (102)	Thailand (91)	USA (75)	Australia (46)	UK (43)
New Zealand	USA (8 853)	Australia (7 861)	UK (6 385)	Germany (3 021)	Canada (2 500)
Papua New Guinea	Australia (375)	USA (197)	UK (103)	Spain (91)	Switzerland (70)
Philippines	USA (1 298)	Japan (909)	Australia (538)	China (500)	UK (410)
Samoa	USA (5)	Australia (4)	Ecuador/Spain/ New Zealand/France/ China/Costa Rica/Fiji/ Chile/Japan/Cook Islands (1)		
Singapore	China (11 179)	USA (10 680)	Australia (4 166)	UK (4 055)	Japan (2 098)
Solomon Islands	Australia (48)	USA (15)	Vanuatu (10)	UK (9)	Fiji (8)
Thailand	USA (6 329)	Japan (4 108)	UK (2 749)	Australia (2 072)	China (1 668)
Tonga	Australia (17)	Fiji (13)	New Zealand (11)	USA (9)	France (3)
Vanuatu	France (49)	Australia (45)	USA (24)	Solomon Islands/ New Zealand/ Japan (10)	
Viet Nam	USA (1 401)	Japan (1 384)	Korea, Rep. (1 289)	France (1 126)	UK (906)

Small or fledgling science systems have very high rates of foreign collaboration

Share of papers with foreign co-authors, 2008–2014



Note: Data are unavailable for some indicators for the Cook Islands, Kiribati, Micronesia, Niue, Samoa, Tonga and Vanuatu.

Source: Thomson Reuters' Web of Science, Science Citation Index Expanded; data treatment by Science–Metrix

COUNTRY PROFILES

AUSTRALIA

End of commodities boom squeezing S&T budgets

Australia continues to play a significant role in STI across the region. Its universities remain a draw for aspiring scientists and engineers from the region and it counts the highest absolute number of FTE researchers and technicians, as well as the highest GERD/GDP ratio (2.25%) and a dynamic business sector which contributes almost two-thirds of GERD (Table 27.2). In 2014, Australia accounted for 54% of the region's papers in the Web of Science (Figure 27.8).

The national innovation system is not without its weaknesses, however. As Australia's Chief Scientist Ian Chubb recently noted, although Australia ranked 17th out of 143 countries in the Global Innovation Index in 2014, it ranked 81st as a converter of raw innovation capability into the output that business needs, namely new knowledge, better products, creative industries and growing wealth. In 2013, Australia's high-tech exports contributed just 1.7% of the total from Southeast Asia and Oceania, ahead of only New Zealand, Cambodia and the Pacific Island states (Figure 27.4). In contrast to many of the ASEAN countries, Australia is not very engaged in product assembly in the global electronics value chain; this illustrates why comparisons of high-tech exports by countries in the region need to take into account the position of each economy in global high-tech production and export.

Australia's economic success in recent decades has been driven largely by the resources boom, primarily in iron ore and coal. Importantly, this has also driven much of R&D investment: 22% of business expenditure on R&D in 2011 concerned the mining sector, which also contributed 13.0% of GERD. The mining sector accounted for 59% of Australian exports in 2013, nearly two-fifths of which consisted in iron ore. Since 2011, the global price for iron ore has dropped from US$ 177 to less than US$ 45 per tonne (July 2015). A major factor behind the fall has been the reduced demand from China and India. Although prices are predicted to stabilize or even rise through 2015, the impact on Australian foreign earnings from this major export sector has been substantial. As a consequence, science in Australia has been hit both by cuts made to R&D expenditure in the mining and minerals sector and by cuts in public funding for science overall.

A new policy direction

Between 2010 and 2013, the majority of policy reports focused on innovation. This has not changed with the current government. The review of the Australian Co-operative Research Centre programme announced in 2014, for instance, has been mandated to explore ways of boosting Australia's productivity and national competitiveness.

The coalition government headed by Tony Abbott has nevertheless introduced changes in the overall direction of STI policy since coming to power in September 2013. In a context of reduced government revenue since the end of the commodities boom, the government's 2014–2015 budget made severe cuts to the country's flagship science institutions. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) faces a reduction of AU$ 111 million (3.6%) over four years and a loss of 400 jobs (9%). The Cooperative Research Centres programme survives but its funding has been frozen at current levels and will be reduced further by 2017–2018. In addition, a number of programmes fostering innovation and commercialization have been abolished. These include some long-running initiatives such as Enterprise Connect, the Industry Innovation Councils and Industry Innovation Precincts. The current government has replaced these incentive schemes with five industry-specific growth centres. The creation of these centres was announced in the government's 2014–2015 budget. Each is to be endowed with a budget of AU$ 3.5 million over four years with a focus on:

- Food and agriculture;
- Mining equipment and services;
- Oil, gas and energy reserves;
- Medical technologies and pharmaceuticals; and
- Advanced manufacturing.

The success of the centres will be measured by business-focused metrics such as increased investment, employment, productivity and sales, reduction in bureaucratic red-tape, improved industry–research linkages and a greater number of businesses integrated into international value chains, in line with the new approach established by the Minister of Industry and Science, Ian Macfarlane, in 2014.

There has been a decisive shift in the present government's approach away from renewable energy and carbon reduction strategies. The Australian carbon tax introduced by the previous Labour government has been abolished and, in the 2014–2015 budget, the government announced plans to abolish the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation. ARENA was established in July 2012 to promote the development, commercialization and dissemination of renewable energy and enabling technologies; it incorporated the Australian Centre for Renewable Energy, which had opened in 2009. However, both ARENA and the Clean Energy Finance Corporation were established by acts of parliament and, although the minister responsible advised parliament in October 2014 that the government was committed to abolishing both agencies, the present government has been unable to obtain majority support from the upper house to repeal the relevant acts.

Not all government research programmes lost out in the 2014–2015 budget. The Antarctic programme was one of its beneficiaries, with provision for a brand new AU$ 500 million icebreaker. This move supports the government strategy of turning the island of Tasmania into a regional hub for Antarctic research and services.

There has also been a shift in priorities in favour of medical research, with the planned establishment of an AU$ 20 billion medical research fund. The fund's creation hinged on a government proposal to abolish free medical treatment under the Medicare system for low-income households, a system that has been in place for two decades, and to replace Medicare with a 'co-payment' levy. The controversial new levy was ultimately defeated in parliament. The proposal is revealing of the current government's philosophy that science is a cost to be recovered from users, rather than a strategic national investment.

The approach to science in the 2014–2015 budget attracted concern from key stakeholder groups. The budget has been described as 'short-sighted' and 'destructive' by the CSIRO and as 'worse than we even imagined' by the Cooperative Research Centres Association. One of Australia's leading professors, Jonathan Borwein, has observed that 'there is more to science than medical research'. In May 2015, the government announced an additional AU$ 300 million in funding for the National Collaborative Research Infrastructure Strategy and committed further financial means in the federal budget for the medical research fund proposed in the 2014–2015 budget.

Another policy development has emerged from a May 2015 review of the Cooperative Research Centres programme. The review recommended a sharper commercial focus and the introduction of shorter-term (three years) co-operative research projects within the overall programme. These recommendations have all been accepted by the current government. Given that no additional funding has been announced for the programme, the sharper commercial focus in future may well come at the expense of the public good at those co-operative research centres oriented towards areas such as climate change and health.

One recent initiative that has drawn support from the scientific community is the creation of a National Science Council to be chaired by the prime minister. Although the Chief Scientist proposed that this would 'help provide strategic thinking for science', the Academy of Science argued that the new council would not compensate for the lack of a science minister. This was a reference to the decision made in December 2014 to entrust the Minister for Industry with the portfolio for science.

Announced in October 2014, the government's *Industry Innovation and Competitiveness Agenda* introduces initiatives to enhance science, engineering and mathematics education but only in the context of how this can contribute to the nation's industrial and economic prospects. There is currently little policy discussion about the importance of science for enhancing the nation's knowledge base or tackling pressing health and environmental problems of both national and global dimensions.

Universities have come to dominate public research

Australian science has historically been built around a strong government research system with four main pillars: the CSIRO, Australian Institute of Marine Science, Australian Nuclear Science and Technology Organisation and the Defence Science and Technology Organisation. State agriculture departments have historically also played a role in agricultural research.

In recent years, however, the university system has become the main focus for government-funded research. Over 70% of the value of public sector research in Australia is now performed by universities, equivalent to 30% of GERD. University research is dominated by medical and health sciences (29%), engineering (10%) and biological sciences (8%). The government research sector, which now performs only 11% of GERD, focuses primarily on the same fields, with the notable addition of agricultural research (19%). The other shares are medical and health sciences (15%), engineering (15%) and biological sciences (11%). This research focus is reflected in the statistics (Figure 27.8).

The government's role has shifted away from supporting public research institutions to becoming a major funder, regulator of standards and assessor of research quality. Many R&D functions formerly carried out by government research agencies have been transferred to the private sector or to universities. This has changed the nature of public funding away from direct appropriations towards a grant system operated through agencies such as the Australian Research Council and the National Health and Medical Research Council, the Cooperative Research Centres Programme and the Rural R&D corporations. The latter corporations, which have been in place now for over 70 years, are a unique Australian mechanism combining public funding with matching producer levies. Government policy emphasizes relevance to industry when allocating competitive research grants, research block grants, doctoral scholarships and university admissions (Australian Government, 2014).

As a consequence, much contemporary policy debate is focusing on how to direct the expanding university research capabilities towards the business sector.

A report commissioned by the Chief Scientist reveals that 11% of Australia's economy relies directly on advanced physical and mathematical sciences, contributing AU$ 145 billion to annual economic activity (AAS, 2015). As we have seen, the strengths of the university and government sectors lie elsewhere and, although the current government intends to foster research of relevance to industry, its focus is on ocean and medical sciences.

The Chief Scientist has also drawn attention to some underlying structural issues in the Australian innovation system, such as the cultural barriers that inhibit both risk-taking behaviour and the flow of people, ideas and funding between the public and private sectors. Laying better pathways between science and its applications will be an urgent challenge for the next decade, if Australia is to emulate more innovative economies.

An academic sector with a regional focus

There are currently 39 Australian universities, three of which are private. In 2013, they had a collective roll of 1.2 million students, 5% of whom (62 471) were enrolled in a master's or PhD programme. This is a much lower percentage than elsewhere in Asia, including Singapore, Malaysia, the Republic of Korea, Pakistan and Bangladesh (Figure 27.5). Moreover, more than 30% of postgraduate students come from overseas and more than half of them (53%) are enrolled in science and engineering fields. This suggests that Australia is producing only a modest number of home-grown scientists and engineers, a trend which may be ringing alarm bells in some policy circles but also underscores Australia's role as a regional hub for the training of scientists.

The growing regional centrality of the Australian higher education system is also reflected in co-authorship trends for scientific publications. Australian authors figure among the top five collaborating countries with all Pacific countries covered in the present chapter and seven out of the nine Southeast Asian countries. The overwhelming international evidence is that collaboration is essential for solving industrial and social problems. Australia is thus uniquely well placed, thanks to its globally recognized public research system and high level of international collaboration (52%). There are sound underlying reasons for seeking to maintain this national leading edge.

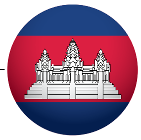
In parallel, the Asian region is rapidly gaining scientific strength. An interesting debate has emerged recently, in which some argue that funding priorities should be directed towards supporting regional research strengths relative to Asian universities. From this perspective, a more nuanced set of priorities emerge, led by ecology, the environment, plant and animal science, clinical medicine, immunology and neuroscience.

A twin challenge for STI

The challenge for STI in Australia is twofold. First, in order to realize the imperative of moving the economy towards more value-added production, there is a need to align public investment in R&D with emerging opportunities for innovative products and services. For example, the declining pre-eminence of coal as the main source of energy for driving global production opens up new scientific opportunities for alternative energies. A decade ago, Australian R&D was well-placed to be at the forefront of this frontier field. Since then, other countries have overtaken Australia but the potential for it to be a leader in this field remains. The proposed industry growth centres and the long-running Cooperative Research Centres programme offer the structure and scientific capacity to underpin such development but the government will also need to utilize policy better to minimize the business-sector risk, in order to capitalize on the science sector's strength in these areas.

An associated challenge will be to ensure that science does not become the hand-maiden of industrial and commercial development. It is Australia's strengths in science and the solidity of its institutions that have enabled the country to become a key regional knowledge hub.

CAMBODIA



A growth strategy that is working

Since 2010, Cambodia has pursued its impressive transformation from a post-conflict state into a market economy. Growth averaged 6.4%per year between 2007 and 2012 and the poverty rate shrank from 48% to 19% of the population, according to the Asian Development Bank's *Country Partnership Strategy 2014–2018*.

Cambodia exports mainly garments and products from agriculture and fisheries but is striving to diversify the economy. There is some evidence of expansion in value-added exports from a low starting point, largely thanks to the manufacture of electrical goods and telecommunications by foreign multinationals implanted in the country.

Higher spending on education, little on R&D

Public expenditure on education accounted for 2.6% of GDP (2010), compared to 1.6% in 2007. The share going to tertiary education remains modest, at 0.38% of GDP or 15% of total expenditure, but it is growing. Despite this, Cambodia still ranks lowest in the region for the education dimension of the World Bank's Knowledge Economy Index.

According to the UNESCO Institute for Statistics, GERD accounts for approximately 0.05% of GDP. As in many of the world's least developed economies, there is a strong reliance on international aid. The regulatory environment in which non-governmental organizations (NGOs) operate is currently a focus of parliamentary debate in Cambodia. It will be interesting to see if any potential legislative change to the regulations reduces R&D investment from the not-for-profit sector.

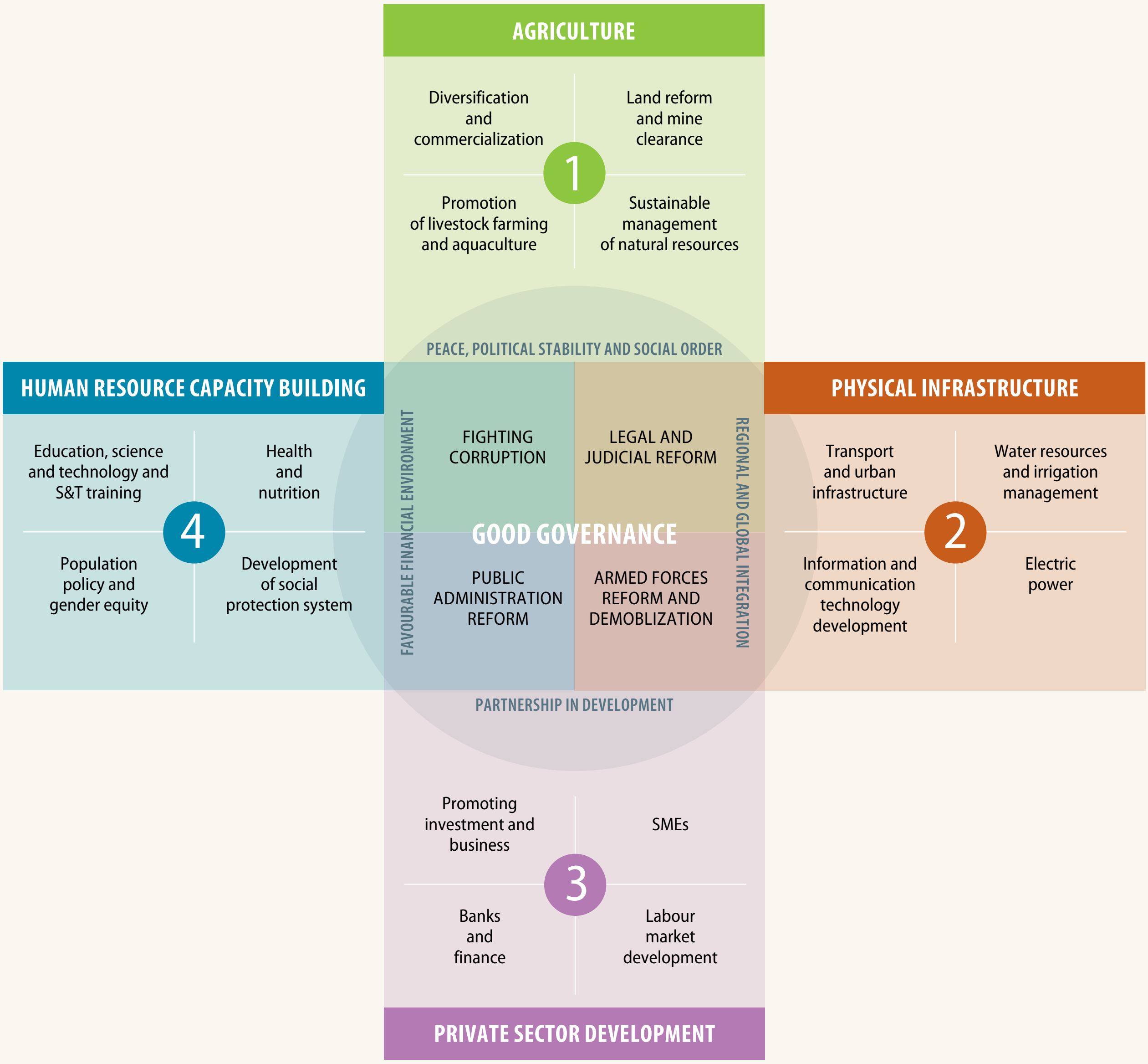
Scientific publications grew by 17% on average between 2005 and 2014, a rate surpassed only by Malaysia, Singapore and Viet Nam (Figure 27.8). They came from a low starting point, however, and had a narrow focus: the majority focused on biological and medical sciences in 2014.

A first national strategy for S&T

Like many low-income countries, Cambodia has been held back by the limited co-ordination of S&T across ministries and the absence of any overarching national strategy for science and development. In 2010, the Ministry of Education, Youth and Support[4] approved a *Policy on Research Development in the Education Sector*. This move represented a first step towards a national approach to R&D across the university sector and the application of research for the purposes of national development.

4. A National Committee for Science and Technology representing 11 ministries has been in place since 1999. Although seven ministries are responsible for the country's 33 public universities, the majority of these institutions come under the umbrella of the Ministry of Education, Youth and Support.

Figure 27.9: **Cambodia's rectangular development strategy, 2013**



Source: Royal Government of Cambodia (2013) *Rectangular Strategy for Growth, Employment, Equity and Efficiency: Phase III.* September, Phnom Penh

This policy was followed by the country's first *National Science and Technology Master Plan 2014–2020*. It was officially launched by the Ministry of Planning in December 2014, as the culmination of a two-year process supported by the Korea International Cooperation Agency (KOICA, 2014). The plan makes provision for establishing a science and technology foundation to promote industrial innovation, with a particular focus on agriculture; primary industry and ICTs.

Another indication that Cambodia is taking a more co-ordinated approach to S&T policy and its integration into the country's wider development plans is Phase III of the government's *Rectangular Development Strategy*, which got under way in 2014. Phase III is intended to serve as a policy instrument for attaining the objectives of the new *Cambodia Vision 2030,* which aims to turn Cambodia into an upper middle-economy by 2030, and the country's *Industrial Development Policy 2015–2025*. The latter were both foreshadowed in the *Rectangular Development Strategy* of 2013, which is significant for having identified specific roles for science (Figure 27.9). The *Industrial Development Policy 2014–2025* was launched in March 2015 and complemented related medium-term strategies, such as the *National Sustainable Development Strategy for Cambodia*, published in 2009 with support from the United Nations Environment Programme and Asian Development Bank, and the *Climate Change Strategic Plan 2014–2023,* published with support from European international development agencies.

A need for a stronger human resource base

The *Rectangular Development Strategy* sets out four strategic objectives: agriculture; physical infrastructure; private sector development; and human capacity-building. Each of these objectives is accompanied by four priority areas for action (Royal Government of Cambodia, 2013). A role for science and technology has been defined in one or more of the priority areas for each 'rectangle' (Figure 27.9). Although science and technology are clearly identified as a cross-cutting strategy for promoting innovation for development, it will be important to co-ordinate and monitor the implementation of priority activities and assess the outcome. The key challenge here will be to build a sufficient human resource base in science and engineering to support the 'rectangular' targets.

Cambodia is likely to remain reliant on international research collaboration and NGO support for some time. Between 2008 and 2013, 96% of Cambodian articles involved at least one international co-author, a trend which may explain the high citation rate. Of note is that Cambodians count both Asian (Thailand and Japan) and Western scientists (USA, UK and France) among their closest collaborators (Figure 27.8). One strategic policy issue will be how to align NGO research support on national strategic plans for development.

Another pressing challenge for Cambodia will be to diffuse human capacity beyond the university sector. The country's narrow economic and scientific base offers some opportunity for growth tied to food production. However, the diffused responsibility for science and technology across 11 key ministries presents challenges for effective policy development and governance. Although there is evidence of growing collaboration across some key agricultural institutions, such as the Cambodian Agricultural Research and Development Institute and the Royal University of Agriculture, difficulties persist in extending this type of collaboration to a broader range of institutions.

One difficulty will be to enhance the technological capacity of the many SMEs active in agriculture, engineering and the natural sciences. Whereas the large foreign firms in Cambodia that are the main source of value-added exports tend to specialize in electrical machinery and telecommunications, the principal task for S&T policy will be to facilitate spillovers in terms of skills and innovation capability from these large operators towards smaller firms and across other sectors (De la Pena and Taruno, 2012).

There is little evidence that the Law on Patents, Utility Model Certificates and Industrial Designs (2006) has been of practical use, thus far, to any but the larger foreign firms operating in Cambodia. By 2012, 27 patent applications had been filed, all by foreigners. Of the 42 applications for industrial design received up to 2012, 40 had been filed by foreigners. Nevertheless, the law has no doubt encouraged foreign firms to introduce technological improvements to their on-shore production systems, which can only be beneficial.

INDONESIA

Ambitious targets for this emerging market economy

By far the most populous country in Southeast Asia, Indonesia is emerging as a middle-income economy with appreciable levels of growth but it has not developed a technology-intensive industrial structure and lags behind comparable economies for productivity growth (OECD, 2013). Since 2012, economic growth has slowed (to 5.1% in 2014) and remains well below the East Asian average. Since taking office in October 2014, President Joko Widodo has inherited the ambitious growth targets enshrined in the *Master Plan for Acceleration and Expansion of Indonesia's Economic Development 2011–2025*: 12.7% growth on average from 2010 to 2025, in order to make Indonesia one of the world's ten largest economies by 2025.

According to World Bank projections, economic growth will accelerate somewhat through 2015– 2017. In the meantime, the volume of high-tech exports remains well below the level of Viet Nam or the Philippines. The same goes for internet access. Although investment in tertiary education has risen since 2007 and Indonesia has no lack of university graduates, enrolment in science remains comparatively low.

Moves to develop industrial research

Much of Indonesia's scientific capacity is concentrated in public research institutions, which employed one in four (27%) researchers by head count in 2009, according to the UNESCO Institute for Statistics. Nine institutions come under the umbrella of the Ministry of Research and a further 18 under other ministries. The majority of researchers (55% by head count) are employed by the country's 400 universities, however, four of which figure in the top 1 000, according to the World Ranking Web of Universities. Researchers publish mainly in life sciences (41%) and geosciences (16%), according to the Web of Science (Figure 27.8). The publication rate has grown since 2010 but at a slower pace than for Southeast Asia overall. Almost nine out of ten articles (86%) have at least one international co-author.

One-third of researchers were employed by industry in 2009, including state-owned enterprises (Figure 27.7). A World Bank loan was announced in 2013 to 'strengthen the bridge' between research and development goals by helping research centres to 'define their strategic priorities and upgrade their human resources to match these priorities' (World Bank, 2014). The big challenge will be to nurture the private sector and encourage S&T personnel to migrate towards it.

The government has put incentive schemes in place to strengthen the linkages between R&D institutes, universities and firms but these focus primarily on the public sector supply side. The co-ordination of research activities by different players may be influenced by the National Research Council (*Dewan Riset Nasional*) chaired by the Ministry of Research and Technology, which groups representatives of ten other ministries and has reported to the president since 1999. However, the National Research Council has a modest budget, equivalent to less than 1% that of the Indonesian Institute of Sciences (Oey-Gardiner and Sejahtera, 2011). Moreover, although it continues to advise the Ministry of Research and Technology, it also advises the Regional Research Councils (*Dewan Riset Daerah*) that have assumed greater significance through the Indonesian decentralization process.

Indonesia's innovation effort is weak on two counts. In addition to the very modest role played by the private sector, the GERD/GDP ratio is negligible: 0.08% in 2009. In 2012, as part of the *Master Plan* to 2025's key strategy for 'strengthening human resource capacity and national science and technology,' the Ministry for Research and Technology released a plan to foster innovation in six economic corridors; this plan still places emphasis primarily on the public sector, despite the government's desire to transfer S&T capacity to industrial enterprises. The plan aims to decentralize innovation policy by establishing regional priorities, which nevertheless remain focused on resource-based industries:

- Sumatra: steel, shipping, palm oil and coal;
- Java: food and beverages, textiles, transport equipment, shipping, ICTs and defence;
- Kalimantan: steel, bauxite, palm oil, coal, oil, gas and timber;
- Sulawesi: nickel, food and agriculture (including cocoa), oil, gas and fisheries;
- Bali – Nussa Tengarra (Lesser Sunda Islands): tourism, animal husbandry and fisheries; and
- Papua – Maluku Islands: nickel, copper, agriculture, oil and gas and fisheries.

The predicted additional economic activity in these six corridors has already inspired a policy recommendation for over US$ 300 million to be directed towards new infrastructure development, to improve power generation and transportation. The government has committed 10% of this amount, the remainder having been provided by state-owned enterprises, the private sector and through public–private partnerships.

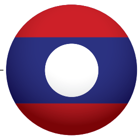
Since taking office, the Joko Widodo government has been focusing on fiscal reform to improve the business environment. His government has not changed the general direction of S&T policies and thus still plans to transfer part of public investment in R&D to the business sector. Recent regulations have sought to increase the level of value-added production in sectors such as the mobile phone industry. A new initiative intended to promote development at the value-added end of the market is a proposal in the 2015 budget to establish a body which would oversee the development of creative industries such as fashion and design. The overall national structure for managing science policy and public sector investment in science remains largely unchanged.

The multi-donor Programme for Eastern Indonesia SME Assistance (PENSA) is currently being evaluated. PENSA was launched in 2003 with the general objective of expanding opportunities for SMEs in Eastern Indonesia. More recently, the emphasis has shifted towards enhancing the financial capacity of SMEs and reforming the business environment. Consequently, by the time PENSA 2 was launched in 2008, it had become a five-year technical assistance programme with a focus on training commercial bank employees in outreach services and improving the regulatory environment and corporate governance among firms in

Eastern Indonesia. The Business Incubator Technology (BIT) programme for SMEs has taken a more direct approach; by 2010, there were up to 20 BIT units at public universities.

The recent policy shift towards creating six economic corridors and linking S&T to development goals is part of an overall strategy to reduce economic dependence on the nation's natural resources. The current trend towards lower global prices for raw materials instils an added urgency.

LAO PEOPLE'S DEMOCRATIC REPUBLIC



Sustainability of rapid resource-based growth in doubt

Lao PDR is one of the poorest countries in Southeast Asia but, thanks to its rich endowment in natural resources (forestry, hydropower, minerals), its strategic location in the midst of a fast-growing region and policies that exploit these advantages, it has been experiencing rapid economic expansion. In 2013, Lao PDR was rewarded for its efforts to liberalize the economy by being admitted to the World Trade Organization; membership should enable the country to become increasingly integrated in the world economy. Thanks to average annual real growth of close to 7.5% for the past 15 years, the poverty rate has halved to 23% in the past two decades. Concerns have nonetheless been raised as to the sustainability of this resource-based growth (Pearse-Smith, 2012).

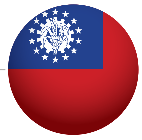
Recent data are unavailable for Lao PDR on R&D expenditure and personnel but the number of scientific publications did increase between 2005 and 2014 by 18% a year, albeit from a very low base (Figure 27.8). Almost all publications throughout this period had international co-authors, mostly from Thailand. As with other countries highly dependent on foreign aid and international scientific collaboration, the current focus on local priorities for development may yet be challenged by broader global interests. At present, Lao PDR has the lowest proportion of researchers of all of ASEAN member states; ASEAN economic integration scheduled for 2015 onwards is likely to provide the country with more opportunities for regional scientific co-operation. The shortage of highly skilled personnel will be less of a challenge for Lao PDR than managing the balancing act of raising the level of skills while simultaneously creating local employment opportunities for the influx of skilled job-seekers.

The premises of an S&T policy framework

As a small economy with a limited capacity in science and engineering, Lao PDR has been actively seeking to build on regional strengths and foster collaboration among Laotian scientists. In 2011, a Ministry of Science and Technology was established. In parallel, representatives of relevant various ministries sit on the National Science Council; the latter was established in 2002 as an advisory board for S&T policy. In 2014, an event was held to improve dialogue between scientists and policy-makers from different sectors of the economy.

Strategies for achieving sustainable development underpin most of the challenges facing Lao PDR. Currently, hydropower and mining account for a large part of the nation's economic output. Balancing the environmental cost with the economic benefit to be gained from these activities will be a challenge.

MYANMAR



A lack of infrastructure to develop markets

Since 2011, Myanmar has been in transition towards a market-based economy. The country is rich in resources such as natural gas (39% of commodity exports), precious stones (14%) and vegetables (12%). Market development is hampered, however, by the lack of infrastructure: telecommunications and internet access remain a luxury and three out of four citizens lack access to electricity.

Geosciences represented 11% of scientific articles between 2008 and 2013, reflecting the importance of fossil fuels for the economy. Two-thirds of Myanmar's modest output nevertheless focused on the biological and medical sciences (Figure 27.8). Nearly 94% of publications had at least one foreign co-author.

There have been some interesting international joint ventures recently involving public and private partners. For example, infrastructure development for the first international standard special economic zone (Thilawa) commenced in 2013 on the outskirts of Yangon. This multi-billion dollar joint venture involves a Japanese consortium (39%), the Japanese government (10%), the Sumitomo corporation and local Myanmar firms (41%), as well as the Myanmar government (10%). Companies in manufacturing, garments, processed foods and electronics industries are among those which plan to establish factories there. Thilawa is expected to be commercially operational by the end of 2015 and should serve as a focal point for future S&T-based collaboration between the public and private sectors.

Pressure on a traditionally solid education system

Historically, Myanmar has enjoyed a solid education sector and comparatively high literacy rates. In recent years, education appears to have suffered, though, from funding shortages and the limited access to international collaboration as a corollary of the sanctions. Overall expenditure on education as a share of GDP fell by about 30% and spending on tertiary education was halved between 2001 and 2011.

There are 161 universities managed by 12 different ministries but researchers claim to have either little or no access to research funding (Ives, 2012). Myanmar nevertheless has the highest proportion of students enrolled in tertiary science degrees (nearly 23%) and the highest proportion of women in science: 87% of all doctoral graduates were women in 2011, including in the sciences.

A need to rationalize the institutional structure of science

The Ministry of Science and Technology has been in place since 1996 but is responsible for only one-third of the country's universities. The Ministry of Education is responsible for a further 64 institutions and the Ministry of Health for another 15. The remaining 21 institutions are the responsibility of nine other ministries. It is very difficult to generate a comprehensive overview of national S&T capability, as there is no single agency responsible for collecting R&D data. The Ministry of Science and Technology has its own database but it reports GERD as accounting for an unrealistic 1.5% of GDP (De la Pena and Taruno, 2012).

One of the biggest challenges facing Myanmar will be to maintain current funding levels for institutional structures that have been in place for some time. It will also be a challenge to reduce the number of ministries responsible for funding and managing the public scientific effort. At present, there appears to be no co-ordinating structure that could serve to align scientific investment with key socio-economic objectives.

NEW ZEALAND

An increasingly Asian–Pacific economy

New Zealand's economy relies heavily on international trade, especially that with Australia, China, the USA and Japan. Exports are dominated by food and beverages (38% in 2013), including some knowledge-intensive products. The main destination for dairy products used to be the UK but, upon integrating the European Economic Community in 1973, the UK also signed up to its common agricultural policy, which effectively excluded external producers from the European market. This forced New Zealand to shift its focus from northern hemisphere markets towards supplying the Asia–Pacific region, which was taking 62% of New Zealand's exports by 2013.

New Zealand is not only one of the few agrarian economies among OECD members. It also has a lower GERD/GDP ratio than many other OECD economies: 1.27% in 2011. Business sector R&D increased slightly between 2009 and 2011 from 0.53% to 0.58% of GDP and thus now contributes just under half of national investment in R&D.

Despite a fairly low R&D intensity, New Zealand scientists are very productive; they authored 7 375 publications in 2014, up by 80% from 2002, with a good citation rate. Globally, New Zealand has the sixth-highest number of scientific articles in relation to GDP, making it the regional leader for this indicator.

International engagement has had a significant impact on New Zealand's national innovation system. Nearly two-thirds of internationalized New Zealand firms undertake at least some type of innovation, such as innovation in goods or services or innovation in marketing methods, whereas only one-third of non-internationalized firms indulge in the same, according to a Business Operations Survey conducted in 2013 by Statistics New Zealand. In the past six years, New Zealand has also upscaled its efforts in science diplomacy (Box 27.1).

Aligning research priorities with national challenges

New Zealand's eight universities play a key role in the country's science system. They account for 32% of GERD, or 0.4% of GDP and employ more than half (57% in FTE) of the country's researchers (2011). In 2010, the government strengthened its own role in the national innovation system by creating a Ministry of Science and Innovation to drive policy-making. In 2012, the ministry was merged with three other agencies, the Ministry of Economic Development, the Department of Labour and the Department of Building and Housing to create what is now the Ministry of Business, Innovation and Employment (MoBIE).

The government established a taskforce in 2010 to reform the country's Crown Research Institutes (CRI), in order to ensure that 'CRIs can best deliver on national priorities and respond to the needs of research users, particularly industry and business' (CRI, 2010). The Crown Research Institutes are the largest dedicated providers of scientific research in New Zealand. Created in 1992, these state enterprises provide core services which earn them operating income. The taskforce's recommendations led to a reform in 2011 which changed the focus of the CRIs from profitability to driving growth and made their priorities more relevant to New Zealand's needs. The CRIs are now responsible for identifying infrastructure needs and formulating policies to provide greater support for innovation, such as through skills development, incentives for business investment in R&D, stronger international linkages and the design of strategies to increase the impact of public research.

Historically, the CRI's priorities have focused on high-value manufacturing services, biological industries, energy and minerals, hazards and infrastructure, environment, health and society. In 2013, the government announced a series of National Science Challenges to identify government priorities for investment in research and provide a more strategic approach to implementing related goals. The first National

Science Challenge in 2010 identified the following ten priority areas for research (MoBIE, 2013):

- Ageing well;
- A better start – improving the potential of young New Zealanders to have a healthy and successful life;
- Healthier lives;
- High value nutrition;
- New Zealand's biological heritage: biodiversity, biosecurity, etc.;
- Our land and water – research to enhance primary sector production and productivity while maintaining and improving the quality of land and water quality for future generations;
- Life in a changing ocean – understanding how to exploit our marine resources within environmental and biological constraints;
- The deep south – understanding the role of the Antarctic and the Southern Ocean in determining our climate and our future environment;
- Science for technological innovation; and
- Resilience to nature's challenges – research into enhancing our resilience to natural disasters.

Box 27.1: **New Zealand: using science diplomacy to make a small voice heard**

Science diplomacy is often viewed as the domain of great powers and associated with megascience projects like the International Space Station. Beneath these high-visibility projects, however, science plays a key role in more discrete and mundane ways in the functioning of the international system.

Under the leadership of Sir Peter Gluckman, Chief Science Advisor to the Prime Minister, New Zealand has been quietly building a number of networks since 2009 that combine science and diplomacy to advance the interests and presence of smaller powers in the international arena. In an era where international economic governance is increasingly seen as the purview of groupings of populous countries like the G8 or the G20, New Zealand's approach acts as a 'canary in the mine' for larger countries, says Prof. Gluckman, alerting them to the particularities of smaller powers which have not always been reflected in the traditional rules-based international architecture.

Science for diplomacy

New Zealand has formed an informal 'coalition of the willing' with other advanced economies of less than 10 million inhabitants. This is a select group: the International Monetary Fund includes just three countries outside Europe in this category: Israel, New Zealand and Singapore. With the addition of the smaller European powers of Denmark, Finland and Ireland, the 'coalition of the willing' currently counts six members.

New Zealand hosts and funds the secretariat of its Small Advanced Economies Initiative. The coalition shares data, analysis, discourse and projects in three areas: public science and higher education; innovation; and economics. A fourth area of co-operation involves 'conversations' between members on how to strengthen national branding and the voice of smaller nations within a broader diplomatic agenda.

Diplomacy for science

As the world's highest emitter of methane per capita, owing to its large population of livestock, New Zealand is particularly keen to promote a science-based international dialogue at the nexus between food security and greenhouse gas emissions from agriculture – agriculture accounting for about 20% of global emissions.

At the climate summit in Copenhagen (Denmark) in 2009, New Zealand proposed creating a Global Research Alliance to Reduce Agricultural Greenhouse Gases. One motivation was also the 'existential concern regarding future market resistance to our farm products'. This alliance currently has 45 members. It is unique in that it is led by scientists, rather than government administrators, in recognition of the fact that countries prefer to spend their research funds within their own border. In Prof. Gluckman's own words, 'here, the diplomatic interests of New Zealand demanded that science be done but, for that science to be done, the diplomats had to create the vehicle then get out of the way.'

Science as aid

In its aid policy, New Zealand makes a special effort to take into account the interests of smaller countries; it focuses on issues such as energy and food security or non-communicable diseases, where the small size of countries is a particular handicap. For instance, New Zealand's priority aid activities in Africa, such as solar-powered electric fence technology, heat-resistant livestock and enhanced forage plant species, all rely on science and its local adaptation.

'I have tried to show how a small country can use science within the diplomatic sphere to protect and advance its interests', says Prof. Gluckman. That argument seems to have borne fruit. New Zealand gained enough support for it to be elected to a non-permanent seat on the United Nations Security Council for the 2015–2016 term.

Source: Based on a lecture given by Prof. Gluckman in June 2015, as part of a summer course on science diplomacy at the World Academy of Sciences.

Read the full speech: www.pmcsa.org.nz/wp-content/uploads/Speech_Science-Diplomacy_Trieste-June-2015-final.pdf

The National Science Challenges fundamentally change New Zealand's research agenda by emphasizing collaboration. Each priority area involves a broad portfolio of multidisciplinary research activities, relying on strong collaboration between researchers and intended end-users, as well as ties to international research.

Challenge funding identified in the 2013 budget provides for an investment of NZ$ 73.5 million (*circa* US$ 57 million) over four years and NZ$ 30.5 million per year thereafter, in addition to the NZ$ 60 million allocated in the 2012 budget. The 2014 budget expanded the Centres of Research Excellence programme and increased the budget for competitive science funding, in order to compensate for the shift in funding to the National Science Challenges. Health and environmental issues remain a key focus for increases through 2015.

Although the government's approach to science policy in the 2014 budget was generally well-received, there is growing concern about an apparent absence of a coherent national strategy for science. Critics have pointed to the need for effective R&D tax credits, for example.

How to make the most of a clean, green brand?

Government investment in science has traditionally been weighted heavily towards primary industries, with the largest sectorial priority, agriculture, receiving 20% of the total. It is thus hardly surprising that scientific publications are concentrated in life sciences (48% of the total in 2014, followed by environmental sciences (14%). A future challenge will be to diversify scientific capacity towards priority areas identified for future growth, such as ICTs, high-value manufacturing and processed primary products, as well as environmental innovation.

As an agricultural trading nation, New Zealand has a great opportunity to embrace 'greener' growth. The government has asked the Green Growth Advisory Group to come up with policy advice on three particularly important topics: how to make the most of a clean, green brand; how to make smarter use of technology and innovation; and how to move businesses towards a lower-carbon economy. The 2012 report by the New Zealand Green Growth Research Trust on *Green Growth: Opportunities for New Zealand* identified no fewer than 21 specific green-growth opportunities in sectors that could enhance New Zealand's competitive advantage in this area, including biotechnology and sustainable agricultural products and services, geothermal energy, forestry and water efficiency.

PHILIPPINES

A desire to reduce disaster risk

Despite a rash of natural disasters in recent years, GDP has pursued moderate growth in the Philippines (Figure 27.2). This growth has been driven largely by consumption that has itself been fuelled by remittances from workers abroad and IT-enabled services, shielding the economy from the lingering weakness of the global economy (World Bank, 2014). Higher economic growth has not substantially reduced poverty, however, which still affects 25% of the population.

The Philippines is one of the world's most vulnerable countries to natural disasters. Every year, between six and nine tropical cyclones make landfall, alongside other extreme events such as floods and landslides. In 2013, the Philippines had the misfortune to lie in the path of Cyclone Haiyan (known as Yolanda in the Philippines), possibly the strongest tropical cyclone ever to hit land, with winds that were clocked at up to 380 kph.

To address disaster risk, the Philippines has been investing heavily in critical infrastructure and enabling tools such as Doppler radars, generating 3D disaster-simulation models from Light Detection and Ranging (LiDAR) technology and the wide-scale installation of locally developed sensors for accurate and timely disaster information nationwide. In parallel, it has been building local capability to apply, replicate and produce many of these technologies.

The decision to promote technological self-reliance to reduce disaster risk is also a feature of the government's approach to inclusive, sustained growth. The revised *Philippine Development Plan 2011–2016* enunciates strategies for using S&T and innovation to boost productivity and competitiveness in agriculture and small businesses, in particular, in sectors and geographical areas dominated by the poor, vulnerable and marginalized.

Building self-reliance in technology

The Department of Science and Technology is the key government institution for science and technology, with policy development being co-ordinated by a series of sectorial councils. Within the framework of the current *National Science and Technology Plan, 2002–2020* (NSTP), the strategic focus is on building technological self-reliance. The *Harmonized Agenda for Science and Technology, 2002–2020* reflects this focus in its approach to problem-solving related to inclusive growth and disaster risk reduction. The *Harmonized Agenda* was presented to the President in August 2014. Although S&T are guided by the NSTP, the *Harmonized Agenda* attempts to provide more detail of how the country can become technologically self-reliant to sustain science and technology beyond the mandate of the current Aquino administration.

The *Harmonized Agenda* focuses on the development of critical technologies such as remote sensing, LiDAR processing, testing and metrology facilities, advanced climate change and weather modelling, advanced manufacturing and high-performance computing. Five centres of excellence are to be established or upgraded by 2020 in biotechnology, nanotechnology, genomics, semiconductors and electronic[5] design.

The five centres of excellence are all government-funded:

- the Centre for Nanotechnology Application in Agriculture, Forestry and Industry (est. 2014) is based at the University of the Philippines Los Baños;
- the Biotech Pilot Plant (est. 2012 and since upgraded) is housed at the University of the Philippines Los Baños;
- the Philippine Genome Centre (est. 2009) is hosted by the University of the Philippines Diliman; it operates two core facilities in DNA sequencing and bioinformatics;
- the Advanced Device and Materials Testing Laboratory is located in the Department of Science and Technology's compound in Bicutan in Taguig City and has been operational since 2013; it houses three laboratories in surface analysis, thermal, chemical and metallurgical analysis;
- the Electronic Product Development Centre will also be located in the Department of Science and Technology's compound in Bicutan in Taguig City; it will provide state-of-the-art design, prototyping and testing facilities for printed circuit boards.

5. Electronic products accounted for 40% of export revenue in April 2013, according to the Semiconductor and Electronics Industry in the Philippines, Inc., which groups 250 Filipino and foreign companies, including Intel.

The Technology Transfer Act (2010) is expected to enhance innovation by providing a framework and support system for the ownership, management, use and commercialization of intellectual property arising from government-funded R&D. To better address needs in terms of human capital, the Fast-Tracked Science and Technology Scholarship Act of 2013 expands the coverage of existing scholarship programmes and strengthens the teaching of science and mathematics in secondary schools. The Philippine National Health Research System Act (2013), meanwhile, has formed a network of national and regional research consortia to boost domestic capacity.

A need to scale up the R&D effort

The Philippines trails its more dynamic ASEAN peers for investment in both education and research. The country invested 0.3% of GDP in higher education in 2009, one of the lowest ratios among ASEAN countries (Figure 27.5). After stagnating for the first half of the century, tertiary enrolment leapt from 2.6 million to 3.2 million between 2009 and 2013. The rise in PhD graduates has been even more spectacular, their number having doubled over the same five-year period from 1 622 to 3 305, according to the UNESCO Institute for Statistics.

Concomitantly, the number of FTE researchers per million inhabitants (just 78 in 2007) and the level of national investment in R&D (0.11% of GDP in 2007) remain low by any standards. Bringing science to underpin future innovation and development is likely to remain a challenge until the level of investment rises. This will include leveraging FDI in areas like electronics, in order to move closer to the higher end of the scale for value-added goods in the global value chain.

Box 27.2: **'Scuba' rice for the Philippines**

The Philippines is one of the most vulnerable countries to the impact of climate change and extreme weather patterns. In 2006, damage caused by cyclones and floods cost the rice industry more than US$ 65 million.

Researchers from the Philippine-based International Rice Research Institute (IRRI) and the University of California in the USA have developed flood-tolerant rice varieties known as 'scuba rice' which can withstand up to two weeks of complete submergence in water. Through marker-assisted backcrossing, researchers transferred the flood-tolerant gene SUB1 into valued local rice varieties. This led to the official release of flood-tolerant local rice varieties across Asia, including the Philippines, in 2009 and 2010.

In 2009, the Philippine National Seed Industry Council approved the release of 'scuba' rice, known locally as 'Submarino rice', with the Philippine Rice Research Institute (PhilRice) acting as distributor.

Since its release, Submarino rice has been distributed by the Department of Agriculture to flood-prone areas across the country, in partnership with IRRI and PhilRice. In pilot farms in the Philippines, this variety has been observed to survive floods with a good yield and less fertilizer use than before, since farmlands receive nutrients from the silt brought by floods.

Critics contest this point. They argue that Submarino rice requires 'a high input of chemical fertilizer and pesticides' and that it is therefore 'not affordable by the majority of poor farmers.' They prefer to endorse alternative growing methods, such as the System of Rice Intensification (see Box 22.2).

Source: Renz (2014); Asia Rice Foundation (2011); IRRI–DFID (2010)

The government's current policy of directing STI towards pressing national problems is laudable. Such an approach also reinforces the economic rationale for government intervention in the science system to address market failures and make markets work within the purview of good governance. A key challenge will be to build sufficiently solid infrastructure to sustain current efforts to solve pressing problems. The idea here has been to promote the thinking that the government has to lay down a set of S&T infrastructure for 'core technologies' that it should fund. There is no better example of the virtues of sustained support for research than the International Rice Research Institute based in the city of Los Baños (Box 27.2 on previous page).

SINGAPORE

From emerging to knowledge economy

Singapore is a small country with no natural resources. In the space of a few decades, it has become by far the wealthiest country in Southeast Asia and Oceania, with GDP per capita of PPP$ 78 763 in 2013, double that of New Zealand, the Republic of Korea or Japan.

The economy receded briefly (-0.6% growth) in 2009, after the global financial crisis reduced international demand for exports and tourism, prompting the government to cut corporate taxes and to dig into its reserves to shore up businesses and save jobs. The economy has since been expanding at a somewhat erratic rate, with 15% growth in 2010 but less than 4% annually since 2012.

Although Singapore's R&D intensity is surpassed only by that of Australia among the countries profiled in the present chapter – and then only by a whisker – its R&D effort appears to have been a casualty of the global financial crisis. In 2006, when GERD represented 2.13% of GDP, the government fixed the target of raising this ratio to 3% by 2010. It was approaching this target in 2008 (2.62%) but GERD has since fallen back to 2.02% in 2012. The contraction in business expenditure on R&D (BERD) since 2008 would seem to be largely responsible for this failure (Figure 27.10). Singapore nevertheless remains an international hub for R&D in the Asia–Pacific region. Moreover, it plans to raise GERD to 3.5% of GDP by 2015.

Scientific publications seem to have been less affected by the recession, even if they have progressed at a more pedestrian pace since 2005 than some other Southeast Asian countries (Figure 27.8). Singapore's scientific output emphasizes engineer-ing research (17% of the total) and physics (11%). This is atypical for the region, where life sciences and geosciences tend to dominate. It is also well above the global average for the share of articles devoted to engineering research (13%) and physics (11%).

Since 2010, Singapore's major universities have gained an international reputation. In 2011, the National University of Singapore and Nanyang University were ranked 40th and 169th respectively in the Times Higher Education World University Rankings. By 2014, they had risen to the 26th and 76th positions respectively.

One cause for concern has been the declining density of technicians (Table 27.1). Whereas the proportion of technicians in Thailand and Malaysia has been rising, it receded by 8% in Singapore between 2007 and 2012. Singapore may benefit from the freer flow of skilled personnel to redress this trend, once the ASEAN Economic Community comes into play in late 2015.

Strengthening domestic innovation to complement FDI

Singapore's economic development is strongly dependent on FDI inflows: inward FDI stock stood at 280% of GDP in 2013, according to UNCTAD. This reflects Singapore's success over the past two decades in persuading multinational corporations to invest in high-tech and knowledge-intensive industries.

Over the past two decades, Singapore has adopted a cluster-based approach to developing its research ecosystem, which now combines both innovative foreign multinationals and endogenous enterprises. Singapore's success rests to a large extent on the alignment of policies designed to leverage national development from a strong multinational presence with policies promoting local innovation. Over the past decade, Singapore has invested heavily in state-of-the-art facilities and equipment and offered attractive salary packages to world-renowned scientists and engineers, driving up Singapore's researcher intensity to one of the highest levels in the world: 6 438 per million inhabitants in 2012 (Table 27.1). In parallel, the government has launched vigorous higher education policies endowed with a generous budget – consistently more than 1% of GDP between 2009 and 2013 – to develop intellectual capital and provide research personnel for both foreign and domestic companies.

Government policies have also focused on developing endogenous capabilities for innovation. Several national research institutions have been grouped into hubs and encouraged to establish ties with renowned knowledge hubs abroad, in order to create centres of excellence in two niche areas: Biopolis (for biomedical research) opened in 2003 and Fusionopolis (for ICTs) in 2008.

It was also in 2008 that Singapore's Research, Innovation and Enterprise Council approved the establishment of a National Framework for Innovation and Enterprise (NFIE). NFIE has two core goals: to commercialize cutting-edge technologies developed by R&D laboratories through the creation of start-up companies; and to encourage universities and polytechnics to pursue academic entrepreneurship and transform the results of their R&D into commercial products. Between 2008 and 2012, S$ 4.4 billion (*circa* US$ 3.2 billion) was allocated under NFIE to fund:

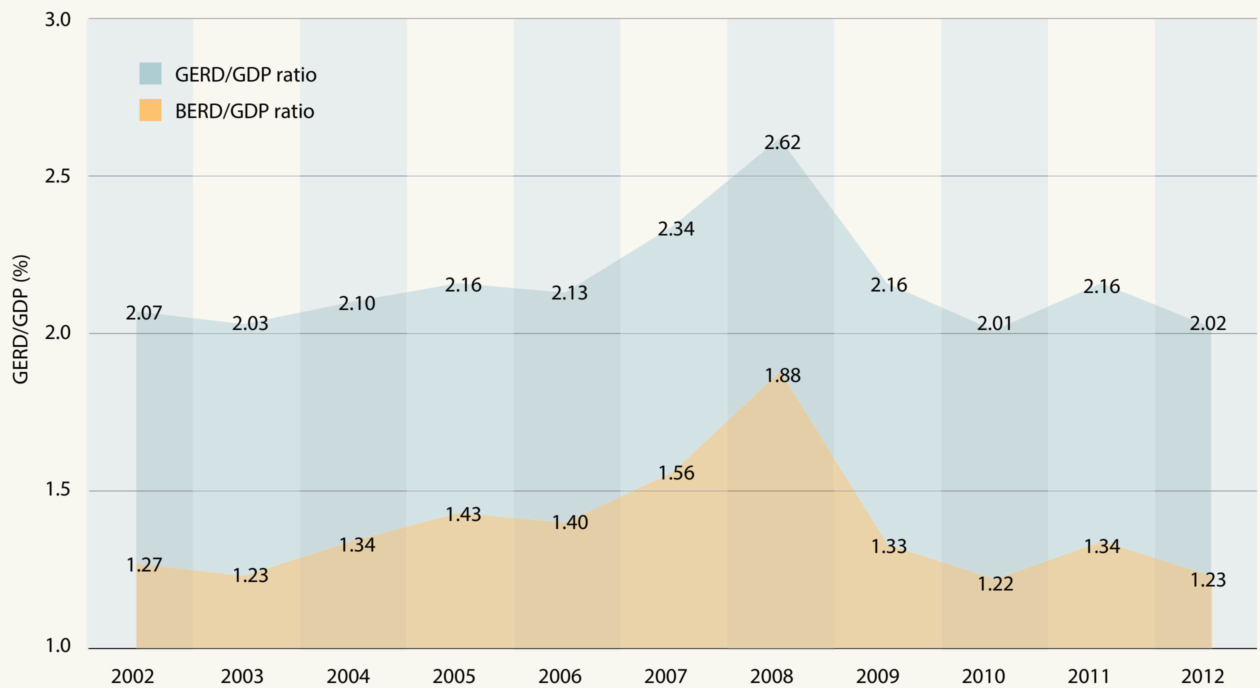
- the establishment of university enterprise boards;
- an innovation and capability vouchers scheme (Box 27.3);
- early-stage venture funding (Box 27.3);
- proof-of-concept grants (Box 27.3);
- a disruptive innovation incubator (Box 27.3);
- a technology incubation scheme (Box 27.3);
- incentives for global entrepreneurial executives to move to Singapore (Box 27.3);
- translational R&D grants for polytechnics to help take research to market;
- national intellectual property principles for publicly funded R&D; and
- the creation of innovation and enterprise institutes.

The National Research Foundation works in tandem with NFIE to provide funding for collaborative innovation (Box 27.3). In parallel, innovation and enterprise institutes have been established to provide an organizational context in which to nurture partnerships and develop funding proposals; that hosted by Singapore Management University, for instance, provides a forum where academics and commercial enterprises can meet. Potential partners can receive guidance from the institute when seeking grants from the National Research Foundation to develop business concepts and seed grants for early-stage development.

The government agency A*STAR has been sponsoring a new initiative for a Smart Nation since November 2014. The aim is to develop new partnerships across the public and private sectors, with a view to strengthening Singapore's capabilities in cybersecurity, energy and transport, in order to 'green' the country and improve public services. In 2015, A*STAR's Institute for Infocomm Research signed an agreement with IBM for the creation of innovative solutions in the areas of big data and analytics, cybersecurity and urban mobility as a contribution to the Smart Nation initiative. In December 2014, the minister in charge of the Smart Nation initiative, Vivian Balakrishnan, had explained[6] the rationale behind the scheme at the opening of the Singapore Maker Festival. The current shift from mass production to mass customization of technology such as mobile phones, combined with lower prices for hardware, the generalization of sensors and easy connectivity, had placed data and innovation at an individual's fingertips, she said. The minister undertook to

6. See: www.mewr.gov.sg/news

Figure 27.10: **Trends in GERD in Singapore, 2002–2012**



Source: UNESCO Institute for Statistics, June 2015

Box 27.3: Innovative ways of financing innovation in Singapore

The National Research Foundation offers enterprises financial support through the following schemes to encourage them to engage in collaborative innovation.

The Incubator for Disruptive Enterprises and Start-ups (IDEAS)
IDEAS was launched jointly by the National Research Foundation and Innosight Ventures Pte Ltd, a Singapore-based venture capital firm. The idea behind IDEAS was to build on the Technology Incubation Scheme established in 2009. Through IDEAS, start-ups with disruptive innovation potential are identified and offered guidance during their early stages. They receive an investment of up to S$ 600 000, 85% of which is provided by the National Research Foundation and the remainder by the incubator. An investment committee evaluates the start-ups. In 2013, the government announced that it would be providing up to S$ 50 million, in order to stimulate the early-stage investment ecosystem.

Innovation and Capability Voucher
Introduced in 2009, the Innovation and Capability Voucher is intended to facilitate the transfer of know-how from knowledge institutions to SMEs. The scheme provides SMEs with funding grants of up to S$ 5 000 to enable them to procure R&D or other services from universities or research institutes.

The scope of the scheme was extended in 2012 to allow the vouchers to be applied in human resource or financial management. The policy expectation is that projects or services purchased from research institutions will lead to upgrades in technology and new products or processes, enhancing knowledge and skills in the process.

Early Stage Venture Fund
Through this fund, the National Research Foundation invests S$ 10 million on a 1:1 ratio in seed venture capital funds that invest in Singapore-based, early-stage high-tech companies.

Proof of Concept Grants
The National Research Foundation administers this scheme, which provides researchers from universities and polytechnics with grants of up to S$ 250 000 for technological projects at the proof-of-concept stage. The government runs a parallel scheme for private enterprises (Spring Singapore).

Technology Incubation Scheme
The National Research Foundation co-invests up to 85% (capped at S$ 500 000) in Singapore-based start-up companies that are being incubated by seeded technology incubators that themselves provide investee companies with physical space, mentorship and guidance.

Global Entrepreneur Executives
This co-investment scheme has been designed to attract high-growth and high-tech venture-backed companies. It targets ICTs, medical technology and clean technology. The objective is to encourage companies to relocate to Singapore. The National Research Foundation invests up to US$ 3 million in matching funding in eligible companies.

Innovation Cluster Programme
This scheme provides funding to strengthen partnerships across businesses, research performers and government in technological areas with potentially large markets. Four plans to develop innovation clusters were funded under this programme in 2013, in diagnostics; speech and language technologies; membranes; and additive manufacturing. Grants for collaborative projects focused on establishing shared infrastructure, capacity-building and on bridging gaps along the value chain.

Source: http://iie.smu.edu.sg; www.spring.gov.sg; www.guidemesingapore.com

make 'as much data as possible' available to the public and promised that, in return, 'if you have got a product or a service that will make life better, pitch it to us'. A Smart Nation Programme Office is being set up in the Prime Minister's Office to bring citizens, the government and industrial players together to identify issues, co-develop prototypes and deploy these effectively.

According to the National Research Foundation, Singapore's long-term goal is to become 'one of the most research-intensive, innovative and entrepreneurial economies in the world, in order to create high-value jobs and prosperity for Singaporeans'. The main challenge for the immediate future will be to expand the role of business enterprises in research and innovation. Singapore's business expenditure on R&D (BERD) is lower than that of R&D-intensive nations with a similarly small population, such as Finland, Sweden or the Netherlands. What distinguishes the latter is the presence of large home-grown multinationals which fund the bulk of BERD. Singapore's BERD, on the other hand, is spread over a far larger number of companies, meaning that a broader segment of industry must be engaged in R&D to increase BERD.

Another challenge will be to sustain the country's advantages and further accelerate collaborative research to internationalize innovation to an even greater extent. One of Singapore's strengths is its capacity to forge influential public–private and public–public partnerships within a compact and integrated research system. Singapore is about to embark upon the next five-year funding tranche for R&D, entitled *Research, Innovation and Enterprise 2020*. This programme will continue to place heavy emphasis on collaborative partnerships within the open innovation paradigm that has worked so well for Singapore up until now, in pursuit of its vision of becoming Asia's innovation capital.

THAILAND

Private sector invests most in value-added chemical goods

Thailand experienced growth of just 27% between 2005 and 2012. Socio-political unrest through the latter part of 2013 and a military *coup d'état* in May 2014 placed the economy at a crossroads. The World Bank (2014) expects consumer and investor confidence to recover once the situation stabilizes. The Thai economy is, nevertheless, likely to remain one of the slowest-growing in Southeast Asia until at least 2016, according to the IMF.

Recent governments have considered it a top priority to promote high-tech manufacturing, in order to stimulate demand. There is certainly evidence of growth in services. However, raising R&D capacity in Thailand will depend very much on private-sector investment, which has accounted for about 40% of GERD in recent years. Given the country's GERD/GDP ratio of 0.39% in 2011, industrial R&D remains low key but this picture could be changing: the Minister of Science and Technology issued a statement in May 2015 claiming a 100% increase in GERD to 0.47% of GDP in 2013 that had been largely driven by private-sector investment.[7]

In light of these statistics, the comparatively high proportion of high-tech exports from Thailand, which account for 10.6% of the total from Southeast Asia and Oceania (Figure 27.4), suggests that high-tech goods may be designed elsewhere and assembled in Thailand, rather than being the fruit of in-house R&D, such as Thai exports of hard disc drives, computers and aeroplane engines. Thailand is the region's biggest exporter of chemical goods: 28% of the total. At present, value-added chemical products are the main focus of private-sector investment in R&D. Clearly, there is a need to develop a business environment that encourages multinational corporations to invest in R&D, as Singapore and Malaysia have done. Thai governments have wrestled with this dilemma but, thus far, have been reticent to offer financial incentives to foreign firms, unlike Malaysia (see Chapter 26).

A major challenge will be to achieve a stable socio-economic environment that is conducive to maintaining FDI, in order to fuel investment in industrial R&D, and to developing higher education of quality. Thailand is still one of the world's largest producers of hard disc drives and light pick-up trucks but maintaining this global edge will require considerable investment in higher education to overcome the skills shortage.

The shortage of both skilled and unskilled labour has remained a chronic problem for Thai businesses (EIU, 2012). Investment in tertiary education was quite high in 2002 (1.1% of GDP) but had fallen to 0.7% of GDP by 2012. Although expenditure on higher education has been slipping as a percentage of GDP, there is a commitment to raising the proportion of students enrolling in science, technology, engineering and mathematics. A pilot programme was initiated in 2008 to establish science-based schools for gifted pupils with a creative streak and a bent for technology (Pichet, 2014). Teaching and learning are project-based, the long-term aim being to help pupils specialize in different fields of technology. Five schools have since been established within this programme:

- the Science-based Technology Vocational College (Chonburi) in central Thailand;
- Lamphun College of Agriculture and Technology in the north (agricultural biotechnology);
- Suranaree College in the northeast (science-based industrial technology);
- Singburi Vocational College (food technology); and
- Phang-nga Technical College in the south (innovation in tourism).

The number of FTE researchers and technicians per million inhabitants increased by 7% and 42% respectively between 2005 and 2009. Researcher density nevertheless remains low, with the great majority of researchers being employed by public research institutes or universities. The National Science and Technology Development Agency (NSTDA) alone employs over 7% of the country's full-time researchers in four institutions: the National Centre for Genetic Engineering and Biotechnology; the National Electronics and Computer Technology Centre; the National Metal and Materials Technology Centre; and the National Nanotechnology Centre.

7. see www.thaiembassy.org/permanentmission.geneva/contents/files/news-20150508-203416-400557.pdf

Ambitious policy targets

Although the *Ten-Year Action Plan for Science and Technology* (2004–2013) introduced the concept of a national innovation system, it did not clearly indicate how to integrate innovation in science and technology. This omission has been remedied by the *National Science, Technology and Innovation Policy and Plan* (2012–2021) adopted in 2012, which identifies avenues for achieving this goal, such as infrastructure development, capacity-building, regional science parks, industrial technology assistance and tax incentives for R&D. Central to the new plan is a commitment to strengthening collaboration between public research agencies and the private sector. The plan also perceives regional development as a potential remedy to the socio-economic disparities which have fuelled social unrest. It fixes a target of raising GERD to 1% of GDP by 2021, with a private-public sector ratio of 70:30.

A complex array of financial incentives target the private sector, including grants or matching grants with innovation coupons, assistance with industrial technology, low-interest loans for innovation and tax incentives to promote the upgrading of skills and technology. The 200% tax reduction for R&D introduced in 2002 to enable companies having invested in R&D to claim a double deduction for their expenses incurred during the same fiscal year has recently been increased to 300%. The statement issued by the Minister of Science and Technology in May 2015 drew attention to the Industrial Technology Assistance Programme for SMEs that includes innovation coupons, loan guarantees and access to ministry-run testing labs. Moreover, a new talent mobility programme allows researchers in universities or government laboratories to be seconded to private firms; under this latter initiative, the firm reimburses the university or research laboratory for the person's salary for the duration of the secondment but importantly, SMEs are exempt from this clause, thanks to a ministerial subsidy which reimburses the laboratory on their behalf. Recent legislative changes now allow for the transfer of ownership of intellectual property from funding agencies to grantees and a new law allows government agencies to set up funds for the commercialization of technology. Collectively, these initiatives are intended to reform the incentive system for R&D.

On the administrative side, there are plans to establish an STI Advisory Committee which will report directly to the Prime Minister. This development should coincide with the transfer of the National STI Policy Office from the Ministry of Science and Technology to the Office of the Prime Minister.

One tambon, one product

Another challenge will be to transfer the knowledge and skills currently concentrated in research institutions and science parks to productive units situated in rural areas, including farms and SMEs.

The One Tambon, One Product programme is being pursued in rural Thailand. Inspired by the One Village, One Product programme in Japan in the 1980s, which sought to combat depopulation, the Thai government introduced the One Tambon, One Product programme (a tambon being a subdistrict) between 2001 and 2006 to stimulate local entrepreneurship and innovative, quality products. A superior product is selected from each tambon for formal branding with one to five stars to indicate the standard of quality before undergoing nationwide promotion. Tambon products include garments and fashion accessories, household goods, foodstuffs and traditional handicrafts. The spread of mobile phone technology into rural areas is opening up opportunities for access to market-based information, as well as product development and modern production processes. The challenge here will be to orient product development towards higher value-added output.

TIMOR-LESTE

Oil-fuelled growth

Since gaining independence in 2002, Timor-Leste's economy has shown healthy growth which is largely attributable to the extraction of natural resources: crude petroleum accounted for 92% of exports in 2014. GDP expanded by 71% between 2005 and 2013, the second-highest rate in the region (Figure 27.2). This has made the young country increasingly independent economically, with overseas development assistance falling steadily from 22.2% of gross national income in 2005 to 6.0% in 2012.

The region's third-biggest spender on higher education

The longer-term objective, set out in the country's *Strategic Development Plan 2011–2030*, is to progress from a low-income to an upper middle-income economy by 2030, like Cambodia. The *Development Plan* emphasizes higher education and training, infrastructure development and the need to reduce dependence on oil. Local capacity-building in science and technology and international scientific collaboration will be key factors in achieving the ambitious targets set out in the plan. These targets are based on the assumption that annual economic growth will maintain a cruising speed of 11.3% through to 2020 and 8.3% through to 2030, thanks largely to a burgeoning private sector. By 2030, there are plans to have at least one hospital in all 13 districts and a specialist hospital in Dili and for at least half of the nation's energy needs to be met by renewable energy sources.

At present, scientific capacity and R&D output are low but the government's massive investment in education is likely to change this picture over the next decade. Between 2009 and 2011, Timor-Leste invested 10.4% of GDP in education, on average, and raised the level of investment in higher education from 0.92% to 1.86% of GDP. It has become the second-biggest spender on higher education in the region, after Malaysia (Figure 27.5).

A review of science education in 2010 drew attention to the need to improve its quality and relevance. Three key sectors have been identified as priorities for future education and training: health and medicine; agriculture; and technology and engineering (Gabrielson *et al.*, 2010). Science, technology, engineering and mathematics have all been targeted as priorities for development across all levels of education, with particular emphasis on higher education.

The main research university in Timor-Leste is the Universidade Nacional de Timor-Lorosae (UNTL) but three smaller universities have opened in recent years and seven institutes also conduct research. At the start of 2011, there was a combined enrolment of 27 010 students across UNTL's 11 campuses, representing an increase of more than 100% since 2004. Enrolment of women increased by 70% from 2009 to 2011. In 2010, UNTL joined the School on Internet Asia Project, which allows under-resourced universities in the region to link up with one other and to benefit from distance learning using low-cost satellite-based internet access.

A need for greater co-ordination and inclusiveness

NGOs play a vital role in Timor-Leste's development but their presence does create problems when it comes to co-ordinating programmes across different government sectors. Whereas the Ministry of Education holds the primary responsibility for higher education, many other agencies are also involved. The *Development Plan* to 2030 cites the objective of 'developing an efficient management system to co-ordinate government interventions in higher education and set priority targets and budgets'. It also cites the establishment of a National Qualifications Framework.

Timor-Leste has one of the lowest levels of connectivity to internet in the world (1.1% in 2013) but mobile phone subscriptions have taken off in the past five years. In 2013, 57.4% of the population had a subscription, compared to 11.9% five years earlier. This suggests that the country's potential for accessing the global information system is growing.

Perhaps Timor-Leste's biggest challenge for the future will be to develop its scientific human capital, so that the country can capitalize on innovation in agriculture and industry to effect its economic transformation. In the meantime, Timor-Leste will need to overcome what has been described as 'Dili-centric' development, in reference to the capital city, and to demonstrate that it has the capacity to make use of new knowledge and information.

VIET NAM

Productivity gains needed to compensate for other losses

Viet Nam has become increasingly integrated into the world economy, particularly since its efforts to liberalize the economy enabled it to join the World Trade Organization in 2007. The manufacturing and service sectors each account for 40% of GDP. However, almost half the labour force (48%) is still employed in agriculture. One million workers a year, out of a total of 51.3 million in 2010, are projected to continue leaving agriculture for the other economic sectors in the foreseeable future (EIU, 2012).

In manufacturing, Viet Nam is expected to lose some of its current comparative advantage in low wages in the near future. It will need to compensate for this loss with productivity gains, if it is to sustain high growth rates: GDP per capita has almost doubled since 2008. High-tech exports from Viet Nam grew dramatically during 2008–2013, particularly with respect to office computers and electronic communications equipment – only Singapore and Malaysia exported more of the latter. A big challenge will be to implement strategies that increase the potential for enhancing technology and skills currently present in large multinational firms to smaller-scale domestic firms. This will require strategies to enhance technical capacity and skills among local firms that are, as yet, only weakly integrated with global production chains.

Since 1995, enrolment in higher education has grown tenfold to well over 2 million in 2012. By 2014, there were 419 institutions of higher education (Brown, 2014). A number of foreign universities operate private campuses in Viet Nam, including Harvard University (USA) and the Royal Melbourne Institute of Technology (Australia).

The government's strong commitment to education, in general, and higher education, in particular (respectively 6.3% and 1.05% of GDP in 2012), has fostered significant growth in higher education but this will need to be sustained to retain academics. Reform is under way. A law passed in 2012 gives university administrators greater autonomy, although the Ministry of Education retains responsibility for quality assurance. The large number of universities and even larger pool of research institutions in Viet Nam presents a serious challenge for governance, particularly with respect to co-ordination among ministries. To some extent, market forces are likely to eliminate the smaller and financially weaker units.

There are no recent data available on R&D expenditure but the number of Vietnamese publications in the Web of Science has increased at a rate well above the average for Southeast Asia. Publications focus mainly on life sciences

(22%), physics (13%) and engineering (13%), which is consistent with recent advances in the production of diagnostic equipment and shipbuilding. Almost 77% of all papers published between 2008 and 2014 had at least one international co-author.

Public–private partnerships key in S&T strategy

The autonomy which Vietnamese research centres have enjoyed since the mid-1990s has enabled many of them to operate as quasi-private organizations, providing services such as consulting and technology development. Some have 'spun off' from the larger institutions to form their own semi-private enterprises, fostering the transfer of public sector S&T personnel to these semi-private establishments. One comparatively new university, Ton Duc Thang (est. 1997), has already set up 13 centres for technology transfer and services that together produce 15% of university revenue. Many of these research centres serve as valuable intermediaries bridging public research institutions, universities and firms. In addition, Viet Nam's most recent Law on Higher Education, passed in June 2012, offers university administrators greater autonomy and there are reports that growing numbers of academic staff are also serving as advisors to NGOs and private firms.

The *Strategy for Science and Technology Development for 2011–2020,* adopted in 2012, builds upon this trend by promoting public–private partnerships and seeking to transform 'public S&T organisations into self-managed and accountable mechanisms as stipulated by law' (MoST, 2012). The main emphasis is on overall planning and priority-setting, with a view to enhancing innovation capability, particularly in industrial sectors. Although the *Strategy* omits to fix any targets for funding, it nevertheless sets broad policy directions and priority areas for investment, including:

- research in mathematics and physics;
- investigation of climate change and natural disasters;
- development of operating systems for computers, tablets and mobile devices;
- biotechnology applied particularly to agriculture, forestry, fisheries and medicine; and
- environmental protection.

The new *Strategy* foresees the development of a network of organizations to support consultancy services in the field of innovation and the development of intellectual property. The *Strategy* also seeks to promote greater international scientific co-operation, with a plan to establish a network of Vietnamese scientists overseas and to initiate a network of 'outstanding research centres' linking key national science institutions with partners abroad.

Viet Nam has also developed a set of national development strategies for selected sectors of the economy, many of which involve S&T. Examples are the *Sustainable Development Strategy* (April 2012) and the *Mechanical Engineering Industry Development Strategy* (2006), together with *Vision 2020* (2006). Spanning the period 2011–2020, these dual strategies call for a highly skilled human resource base, a strong R&D investment policy, fiscal policies to encourage technological upgrading in the private sector and private-sector investment and regulations to steer investment towards sustainable development.

PACIFIC ISLAND COUNTRIES

Small states with big development needs

Pacific Island economies are mostly dependent on natural resources, with a tiny manufacturing sector and no heavy industry. The trade balance is more skewed towards imports than exports, with the exception of Papua New Guinea, which has a mining industry. There is growing evidence that Fiji is becoming a re-export hub in the Pacific; between 2009 and 2013, its re-exports grew threefold, accounting for more than half of all exports by Pacific Island states. Now that it has joined the World Trade Organization (in 2012), Samoa can also expect to become more integrated in global markets.

The wider cultural and social context heavily influences science and technology in the Pacific Island countries. Furthermore, limited freedom of expression and, in some cases, religious conservatism discourage research in certain areas. This said, the experience of these countries shows that sustainable development and a green economy can benefit from the inclusion of traditional knowledge in formal science and technology, as underlined by the *Sustainable Development Brief* prepared by the Secretariat of the Pacific Community in 2013.

The *UNESCO Science Report 2010* observed that the lack of national and regional policy frameworks was a major stumbling block for developing integrated national STI agendas. Pacific Island states have since moved forward in this regard by establishing a number of regional bodies to address technological issues for sectorial development.

Examples are the:

- Secretariat of the Pacific Community for climate change, fisheries and agriculture;
- Pacific Forum Secretariat for transport and telecommunications; and
- Secretariat of the Pacific Region Environmental Programme for related issues.

Unfortunately, none of these agencies has a specific mandate for S&T policy. The recent establishment of the Pacific–Europe Network for Science, Technology and Innovation (PACE-Net Plus) goes some way towards filling this void, at least temporarily. Funded by the European Commission within its Seventh Framework Programme for Research and Innovation (2007–2013), this project spans the period 2013–2016 and thus overlaps with the European Union's Horizon 2020 programme (see Chapter 9). Its objectives are to reinforce the dialogue between the Pacific region and Europe in STI; to support biregional research and innovation through calls for research proposals and to promote scientific excellence and industrial and economic competition. Ten of its 16 members[8] come from the Pacific region.

PACE-Net Plus focuses on three societal challenges:

- Health, demographic change and well-being;
- Food security, sustainable agriculture, marine and maritime research and the bio-economy; and
- Climate action, resource efficiency and raw materials.

PACE–Net Plus has organized a series of high-level policy dialogue platforms alternately in the Pacific region and in Brussels, the headquarters of the European Commission. These platforms bring together key government and institutional stakeholders in both regions, around STI issues.

A conference held in Suva (Fiji) in 2012 under the umbrella of PACE–Net Plus produced recommendations for a strategic plan[9] on research, innovation and development in the Pacific. The conference report published in 2013 identified R&D needs in the Pacific in seven areas: health; agriculture and forestry; fisheries and aquaculture; biodiversity and ecosystem management; freshwater; natural hazards; and energy. Noting the general absence of regional and national STI policies and plans in the Pacific, the conference also established the Pacific Islands University Research Network to support intra- and inter- regional knowledge creation and sharing and to prepare succinct recommendations for the development of a regional STI policy framework. This policy framework was supposed to be informed by evidence gleaned from measuring STI capability but the absence of data presents a formidable barrier. This formal research network will complement the Fiji-based University of the South Pacific, which has campuses in other Pacific Island countries.

8. The ten are the: Australian National University, Montroix Pty Ltd (Australia), University of the South Pacific, Institut Malardé in French Caledonia, National Centre for Technological Research into Nickel and its Environment in New Caledonia, South Pacific Community, Landcare Research Ltd in New Zealand, University of Papua New Guinea, Samoa National University and the Vanuatu Cultural Centre.

9. See: http://pacenet.eu/news/pacenet-outcomes-2013

In 2009, Papua New Guinea articulated its *National Vision 2050*, which led to the establishment of a Research, Science and Technology Council. *Vision 2050*'s medium-term priorities include:

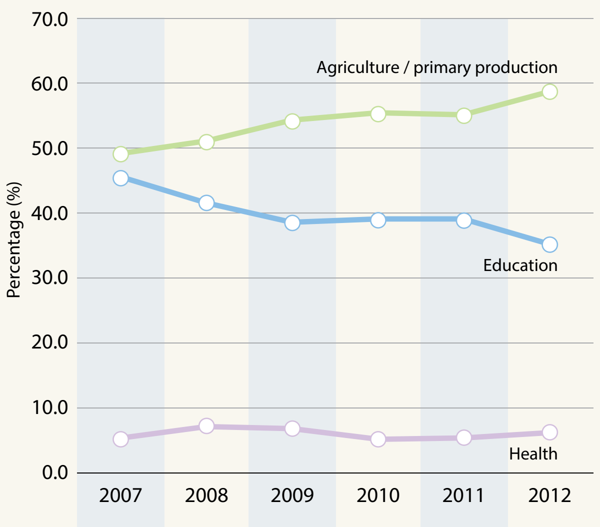
- emerging industrial technology for downstream processing;
- infrastructure technology for the economic corridors;
- knowledge-based technology;
- S&T education; and
- the ambitious target of investing 5% of GDP in R&D by 2050.

At its gathering in November 2014, the Research, Science and Technology Council re-emphasized the need to focus on sustainable development through science and technology. Moreover, in its *Higher Education Plan III 2014–2023*, Papua New Guinea sets out a strategy for transforming tertiary education and R&D through the introduction of a quality assurance system and a programme to overcome the limited R&D capacity.

Like Papua New Guinea, Fiji and Samoa consider education to be one of the key policy tools for driving STI and modernization. Fiji, in particular, has made a supreme effort to re-visit existing policies, rules and regulations in this sector. The Fijian government allocates a larger portion of its national budget to education than any other Pacific Island country (4% of GDP in 2011), although this is down from 6% of GDP in 2000. The proportion of the education budget allocated to higher education has fallen slightly, from 14% to 13%, but scholarship schemes like National Toppers, introduced in 2014, and the availability of student loans have made higher education attractive and rewarding in Fiji. Many Pacific Island countries take Fiji as a benchmark: the country draws education leaders from other Pacific Island countries for training and, according to the Ministry of Education, teachers from Fiji are in great demand in these countries.

According to an internal investigation into the choice of disciplines in school-leaving examinations (year 13), Fijian students have shown a greater interest in science since 2011. A similar trend can be observed in enrolment figures at all three Fijian universities. One important initiative has been the creation of the Higher Education Commission (FHEC) in 2010, the regulatory body in charge of tertiary education in Fiji. FHEC has embarked on registration and accreditation processes for tertiary-level education providers to improve the quality of higher education in Fiji. In 2014, FHEC allocated research grants to universities with a view to enhancing the research culture among faculty.

Figure 27.11: **Government expenditure on R&D in Fiji by socio-economic objective, 2007–2012**



Source: Fiji Bureau of Statistics, 2014

Fiji is the only Pacific Island country with recent data for GERD. The national Bureau of Statistics cites a GERD/GDP ratio of 0.15% in 2012. Private-sector R&D is negligible. Between 2007 and 2012, government investment in R&D tended to favour agriculture (Figure 27.11). Scientists publish much more in geosciences and medical sciences than in agricultural sciences, however (Figure 27.8).

According to the Web of Science, Papua New Guinea had the largest number of publications (110) among Pacific Island states[10] in 2014, followed by Fiji (106). These publications concerned mainly life sciences and geosciences. A noticeable feature of scientific publications from French Polynesia and New Caledonia is the emphasis on the geosciences: six to eight times the world average for this field. Conversely, nine out of ten scientific publications from Papua New Guinea concentrate on immunology, genetics, biotechnology and microbiology.

Fijian research collaboration with North American partners exceeded that with India between 2008 and 2014 – a large proportion of Fijians are of Indian origin – and was concentrated in a handful of scientific disciplines, such as medical sciences, environmental sciences and biology. International co-authorship was higher for Papua New Guinea and Fiji (90% and 83% respectively) than for New Caledonia and French Polynesia (63% and 56% respectively). Research partnerships also involved countries in Southeast Asia and Oceania, as well as the USA and Europe. Surprisingly, there was little co-authorship with authors based in France, with the notable exception of Vanuatu (Figure 27.8).

Having 100% foreign co-authors has its drawbacks

A near-100% rate of international co-authoring can be a double-edged sword. According to the Fijian Ministry of Health, research collaboration often results in an article being published in a reputed journal but gives very little back in terms of strengthening health in Fiji. A new set of guidelines are now in place in Fiji to help build endogenous capacity in health research through training and access to new technology. The new policy guidelines require that all research projects initiated in Fiji with external bodies demonstrate how the project will contribute to local capacity-building in health research. The Ministry of Health itself is seeking to develop endogenous research capacity through the *Fiji Journal of Public Health*, which it launched in 2012. In parallel, the Ministry of Agriculture revived Fiji's *Agricultural Journal* in 2013, which had been dormant for 17 years. In addition, two regional journals were launched in 2009 as a focus for Pacific scientific research, the *Samoan Medical Journal* and the *Papua New Guinea Journal of Research, Science and Technology*.

Fiji leading growth in ICTs

Access to the internet and mobile phone technologies has increased considerably across the Pacific Island countries in the past few years. Fiji shows substantial growth in this field, supported by its geographical location, service culture, pro-business policies, English-speaking population and well-connected e-society. Relative to many other South Pacific Islands, Fiji has a fairly reliable and efficient telecommunications system with access to the Southern Cross submarine cable linking New Zealand, Australia and North America. A recent move to establish the University of the South Pacific Stathan ICT Park, the Kalabo ICT economic zone and the ATH technology park in Fiji should boost the ICT support service sector in the Pacific region.

Tokelau first to generate all electricity from renewable sources

On average, 10% of the GDP of Pacific Island countries funds imports of petroleum products but in some cases this figure can exceed 30%. In addition to high fuel transport costs, this reliance on fossil fuels leaves Pacific economies vulnerable to volatile global fuel prices and potential spills[11] by oil tankers. Consequently, many Pacific Island countries are convinced that renewable energy will play a role in their countries' socio-economic development. In Fiji, Papua New Guinea, Samoa and Vanuatu, renewable energy sources already represent significant shares of the total electricity supply: 60%, 66%, 37% and 15% respectively. Tokelau has even become the first country in the world to generate 100% of its electricity using renewable sources.

10. They are not covered in the present chapter but the French territories of New Caledonia and French Polynesia had 116 and 58 publications catalogued in the Web of Science in 2013.

11. See: www.pacificenergysummit2013.com/about/energy-needs-in-the-pacific

Targets for developing sustainable energy

New targets for many Pacific Island countries were established between 2010 and 2012 (Tables 27.3 and 27.4) and efforts are under way to improve countries' capacity to produce, conserve and use renewable energy. For example, the EU has funded the Renewable Energy in Pacific Island Countries Developing Skills and Capacity programme (EPIC). Since its inception in 2013, EPIC has developed two master's programmes in renewable energy management and helped to establish two Centres of Renewable Energy, one at the University of Papua New Guinea and the other at the University of Fiji. Both centres became operational in 2014 and aim to create a regional knowledge hub for the development of renewable energy. In February 2014, the EU and the Pacific Islands Forum Secretariat signed an agreement for a programme on Adapting to Climate Change and Sustainable Energy worth € 37.26 million which will benefit 15 Pacific Island[12] states.

12. Cook Islands, Fiji, Kiribati , Marshall Islands, Federated States of Micronesia, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu and Vanuatu

Climate change a common concern

In the Pacific region, climate change mostly concerns marine issues, such as rising sea levels and the increased salinity of soils and groundwater, whereas, in Southeast Asia, carbon reduction strategies are a major focus. Disaster resilience, on the other hand, resonates with both regions.

Climate change seems to be the most pressing environmental issue for Pacific Island countries, as it is already affecting almost all socio-economic sectors. The consequences of climate change can be seen in agriculture, food security, forestry and even in the spread of communicable diseases. The Secretariat of the Pacific Community has initiated several activities to tackle problems associated with climate change. These cover a great variety of areas, such as fisheries, freshwater, agriculture, coastal zone management, disaster management, energy, traditional knowledge, education, forestry, communication, tourism, culture, health, weather,

Table 27.3: **National renewable energy targets for selected Pacific Island states, 2013–2020**

Country	Energy Target	Timeframe
Cook Islands	50% of energy demand provided by renewable energy by 2015 and 100% by 2020	2015 and 2020
Fiji	90% renewable	2015
Nauru	50% renewable	2015
Palau	20% renewable and a 30% reduction in energy consumption	2020
Samoa	10% renewable	2016
Tonga	50% renewable and the overall energy cost reduced by 50%	2015
Vanuatu	33% renewable, target fixed by UNELCO (a private company)	2013

Source: Secretariat of the Pacific Community (2013) *Sustainable Development Brief*

Table 27.4: **Fiji's Green Growth Framework, 2014**

Focus area	Strategy
Support research and innovation in green technologies and services	■ support existing green industries by subsidizing firms that use green technologies throughout the production value chain; ■ increase public research funding for refining and improving existing technologies, such as the Ocean Centre for Sustainable Transport; ■ develop a national framework for promoting innovation and research into environmentally sustainable technologies by the end of 2017.
Promote the use of green technologies	■ increase public awareness of green technologies; ■ measure the success of public school environmental education; ■ examine the potential for tariffs on non-green technology imports; ■ reduce import duties on low carbon technologies; ■ introduce incentives for large-scale FDI in industries that develop environmentally sustainable technology in areas such as transport, energy, manufacturing and agriculture.
Develop national innovative capabilities	■ develop a strategy for science and technology, innovation and R&D that is integrated in an overall sustainable development strategy across all thematic areas by the end of 2017; ■ ensure that at least 50% of secondary school teachers are trained to implement the revised Fiji National Curriculum Framework by 2020.

Source: Ministry of Strategic Planning and National Development and Statistics (2014) *A Green Growth Framework for Fiji: Restoring the Balance in Development that is Sustainable for our Future.* Suva gender implications and biodiversity. Almost all Pacific Island countries are involved in one or more of these activities.

Several projects related to climate change are also being co-ordinated by UNEP, within the Secretariat of the Pacific Region Environmental Programme (SPREP). The aim of SPREP is to help all members improve their 'capacity to respond to climate change through policy improvement, implementation of practical adaptation measures, enhancing ecosystem resilience to the impacts of climate change and implementing initiatives aimed at achieving low-carbon development'.

The first major scheme focusing on adaptation to climate change and climate variability dates back to 2009. Pacific Adaptation to Climate Change involves 13 Pacific Island nations, with international funding from the Global Environment Facility, as well as from the US and Australian governments.

Using S&T to foster value-added production in Fiji

The desire to ensure that fisheries remain sustainable is fuelling the drive to use S&T to make the transition to value-added production. The fisheries sector in Fiji is currently dominated by the catch of tuna for the Japanese market. The Fijian government plans to diversify this sector through aquaculture, inshore fisheries and offshore fish products such as sunfish and deep-water snapper. Accordingly, many incentives and concessions are being offered to encourage the private sector to invest in these areas.

Another priority area in the Pacific is agriculture and food security. The *Fiji 2020–Agriculture Sector Policy Agenda* (MoAF, 2014) draws attention to the need to build a sustainable community and gives high priority in the development agenda to ensuring food security. Strategies outlined in *Fiji 2020* include:

- modernizing agriculture in Fiji;
- developing integrated systems for agriculture;
- improving delivery of agricultural support systems;
- enhancing innovative agricultural business models; and
- strengthening the capacity for policy formulation.

Fiji has taken the initiative of shifting away from subsistence agriculture towards commercial agriculture and agro-processing of root crops, tropical fruits, vegetables, spices, horticulture and livestock.

Little use of technology in forestry

Forestry is an important economic resource for Fiji and Papua New Guinea. However, forestry in both countries uses low- and semi-intensive technological inputs. As a result, product ranges are limited to sawed timber, veneer, plywood, block board, moulding, poles and posts and wood chips. Only a few limited finished products are exported. Lack of automated machinery, coupled with inadequately trained local technical personnel, are some of the obstacles to introducing automated machinery and design. Policy-makers need to turn their attention to eliminating these barriers, in order for forestry to make a more efficient and sustainable contribution to national economic development.

The blueprint for the subregion's sustainable development over the coming decade is the *Samoa Pathway*, the action plan adopted by countries at the third United Nations Conference on Small Island Developing States in Apia (Samoa) in September 2014. The *Samoa Pathway* focuses on, *inter alia*, sustainable consumption and production; sustainable energy, tourism and transportation; climate change; disaster risk reduction; forests; water and sanitation, food security and nutrition; chemical and waste management; oceans and seas; biodiversity; desertification, land degradation and drought; and health and non-communicable diseases.

CONCLUSION

A need to find a balance between local and global engagement in problem-solving

Leaving aside for the moment the region's four leaders for R&D intensity – Australia, Malaysia, New Zealand and Singapore – most countries covered in the present chapter are small both economically and in terms of their scientific production. It is thus not surprising to find an extremely high proportion of researchers in these countries who collaborate more or less systematically with the more scientifically prolific countries in the region and with scientists from knowledge hubs in North America, Europe and elsewhere in Asia. For the less developed economies in the Southeast Pacific and Oceania, co-authorship is in the range of 90–100% and such collaboration appears to be growing. This trend can be of benefit not only for the low income countries but also for global science when it comes to tackling regional problems associated with food production, health, medicine and geo-technical issues. However, the issue for the smaller economies is whether output dominated by international scientific collaboration is steering research in the direction envisaged by national S&T policies or whether research in these less developed countries is being driven by the particular interests of foreign scientists.

We have seen that multinational corporations have gravitated towards Cambodia and Viet Nam in recent years. Despite this, the number of patents granted for these two countries is negligible: four and 47 patents respectively over the period from 2002–2013. Even though 11% of the region's high-tech exports came from Viet Nam in 2013, according to the

Comtrade database, the majority of high-tech exports from Viet Nam (and no doubt Cambodia, too, but data are lacking) were designed elsewhere and simply assembled in the host country. Even if foreign firms *do* intensify their in-house R&D in the low income country that hosts them, this will not necessarily boost capacity for science and technology in the host country. Unless there is a sufficient number of trained personnel and strong institutional capabilities, R&D will continue to take place elsewhere. The rapid growth of FDI in R&D in India and China, where there has been parallel growth in the availability of local skills, is the outcome of strategic business decisions. The alternative for developing economies such as Viet Nam and Cambodia is to draw on the knowledge and skills embedded in the activities of large foreign firms, in order to develop the same level of professionalism among local suppliers and firms. By encouraging foreign high-tech manufacturers to run training programmes in the host country, governments will also be drawing manufacturers into national training strategies, with positive spin-offs for both producers and suppliers. A more technically advanced supply chain that is capable of absorbing new skills and knowledge should, in turn, encourage foreign firms to invest in R&D, with a flow-on benefit to local firms.

Regional blocs are playing an important role in science and technology across the region. We have seen that ASEAN is monitoring and co-ordinating developments in science and moving towards the free flow of skilled personnel across its member states. APEC has recently completed a study of skills shortages in the region with a view to setting up a monitoring system to address training needs before shortages become critical. Pacific Island countries have initiated a number of networks to foster research collaboration and solutions to deal with climate change.

The end of the commodities boom since 2013 has led resource-rich economies to devise S&T policies that can reinvigorate economic alternatives in areas in which countries show strengths, such as life sciences for Australia and New Zealand or engineering for some Asian countries. There is a growing tendency for policy to integrate innovation into S&T policies and STI strategies into longer-term development plans.

To some extent, this trend has created a dilemma for science and, in particular, for scientists. On the one hand, there is a strong imperative to produce quality scientific research and the metric for measuring quality is essentially scientific output in peer-reviewed journals. The careers of academic researchers and those in public research institutions depend upon it, yet many national development plans are also seeking research relevance. Clearly, both imperatives are important for fostering development and international competitiveness. The richer countries have the economic opportunity to pursue advances in basic research and to build a deeper and broader science base. Lower-income economies, however, face accrued pressure to favour relevance. Maintaining career paths for scientists that allow them to pursue both quality and relevance will remain a challenge.

Today, most policies across Southeast Asia and Oceania are oriented towards sustainable development and managing the consequences of climate change. The most notable exception is Australia. To some extent, the focus on sustainable development is probably driven by global concerns and the imminent adoption of the United Nations' Sustainable Development Goals in September 2015. Global engagement is far from the only motivation, however. Rising sea levels and increasingly frequent and virulent hurricanes are threatening agricultural production and freshwater quality and are thus of direct concern to most countries in the region. In turn, global collaboration will remain an important strategy for resolving these local issues.

KEY TARGETS FOR SOUTHEAST ASIA AND OCEANIA

- Attain economic growth of 12.7% on average in Indonesia from 2010 to 2025, in order to become one of the world's ten largest economies by 2025;
- Raise GERD to 1% of GDP in Thailand by 2021, with the private sector contributing 70% of GERD;
- Raise GERD to 3.5% of GDP in Singapore by 2015 (2.1% in 2012);
- By 2030, ensure that all 13 districts in Timor-Leste have at least one hospital and that there is a specialist hospital in Dili, with at least half of the nation's energy needs to be met by renewable energy sources;
- Raise the share of renewable energy by 2015–2016 in the following Pacific Island nations to: Cook Islands, Nauru and Tonga (50%), Fiji (90%) and Samoa (10%).

REFERENCES

AAS (2015) *The Importance of Advanced Physical and Mathematical Sciences to the Australian Economy.* Australian Academy of Science: Canberra.

Asia Rice Foundation (2011) *Adaptation to Climate Variability in Rice Production*. Los Baños, Laguna (Philippines).

A*STAR (2011) *Science, Technology and Enterprise Plan 2015: Asia's Innovation Capital.* Singapore.

Brown, D. (2014) *Viet Nam's Education System: Still under Construction*. East Asia Forum, October.

CHED (2013) *Higher Education Institutions.* Philippines. Commission on Higher Education of the Philippines: Manila.

CRI (2010) *How to Enhance the Value of New Zealand's Investment in Crown Research Institutes*. Crown Research Institutes Taskforce. See: www.msi.govt.nz.

De la Pena, F. T. and W. P. Taruno (2012) *Study on the State of S&T Development in ASEAN.* Committee on Science and Technology of Association for Southeast Asian Nations: Taguig City (Philippines).

EIU (2012) *Skilled Labour Shortfalls in Indonesia, the Philippines, Thailand and Viet Nam.* A custom report for the British Council. Economist Intelligence Unit: London.

ERIA (2014) *IPR Protection Pivotal to Myanmar's SME development and Innovation*. Press release by Economic Research Institute for ASEAN and East Asia. *See:* www.eria.org

Gabrielson, C.; Soares, T. and A. Ximenes (2010) *Assessment of the State of Science Education in Timor Leste. Ministry of Education of Timor-Leste.* *See:* http://competence-program.asia.

Government of Australia (2014) *Australian Innovation System Report: 2014.* Department of Industry: Canberra.

Government of Indonesia (2011) *Acceleration and Expansion of Indonesia Economic development 2011–2025.* Ministry for Economic Affairs: Jakarta.

Government of Timor-Leste (2011) *Timor-Leste Strategic Development Plan: 2011–2030.* Submitted to national parliament.

Hurst, D. (2015) China and Australia formally sign free trade agreement. *The Guardian*, 17 June.

IRRI–DFID (2010) *Scuba Rice: Breeding Flood-tolerance into Asia's Local Mega Rice Varieties*. Case study. International Rice Research Institute and UK Department for International Development.

Ives, M. (2012) Science competes for attention in Myanmar reforms. See: www.scidev.net/global/science-diplomacy/feature/science-competes-for-attention-in-myanmar-s-reforms.html.

KOICA (2014) Cambodia National Science & Technology Master Plan 2014-2020. *KOICA Feature News,* October. Release by Korea International Cooperation Agency.

MoBIE (2013) *National Science Challenges Selection Criteria.* Ministry of Business, Innovation and Employment of New Zealand: Wellington.

MoEYS (2010*) Policy on Research and Development in the Education Sector*. Ministerial meeting, July. Ministry of Education, Youth and Sport of the Kingdom of Cambodia: Phnom Penh.

MoSI (2012) *2012-2015 Statement of Intent*. Ministry of Science and Innovation of New Zealand: Wellington.

MoST (2012*) The Strategy for Science and Technology Development for the 2011–2020 Period.* Ministry of Science and Technology of the Socialist Republic of Viet Nam: Ho Chi Minh City.

NEDA (2011) *Philippines Development Plan 2011–2016 Results Matrices*. National Economic and Development Authority: Philippines.

NRF (2012) *National Framework for Research, Innovation and Enterprise*. National Research Foundation of Singapore. *See:* www.spfc.com.sgdf

OECD (2013) *Innovation in Southeast Asia*. Organisation for Economic Cooperation and Development. OECD Publishing. *See:* http://dx.doi.org/10.1787/9789264128712-10-en.

Oey-Gardiner, M. and I. H. Sejahtera (2011) *In Search of an Identity for the DRN. Final Report*. Commissioned by AusAID.

Pearse-Smith, S. (2012) The impact of continued Mekong Basin hydropower development on local livelihoods. *Consilience: The Journal of Sustainable Development*, 7 (1): 73–86.

Perkins, N. I. (2012) Global priorities, local context: a governance challenge. *SciDev.net*. *See:* www.scidev.net/global/environment/ nuclear/.

Pichet, D. (2014) Innovation for Productive Capacity-building and Sustainable Development: Policy Frameworks, Instruments and Key Capabilities. National Science Technology and Innovation Policy Office, Thailand, UNCTAD presentation, March.

Renz, I. R. (2014) Philippine experts divided over climate change action. *The Guardian*, 8 April.

Socialist Republic of Vietnam (2013) *Defining the functions, tasks, powers and organizational structure of Ministry of Science and Technology*. Decree No: 20/2013/ND-CP. Hanoi.

Sugiyarto, G. and D. R. Agunias (2014) A 'Freer' Flow of Skilled Labour within ASEAN: Aspirations, Opportunities and Challenges in 2015 and Beyond. Issue in Brief, no. 11. Migration Policy Institute, International Office for Migration: Washington D.C.

UIS (2014) *Higher Education in Asia: Expanding Out, Expanding Up*. UNESCO Institute for Statistics: Montreal.

World Bank (2014) *Enhancing Competitiveness in an Uncertain World.* October. World Bank Group: Washington.

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Annexes

Annex 1: Composition of regions and sub-regions

Groupings mentioned in Chapter 1

COUNTRIES BY INCOME LEVELS[1]

High-income economies
Antigua and Barbuda; Australia; Austria; Bahamas; Bahrain; Barbados; Belgium; Brunei Darussalam; Canada; Chile; China, Hong Kong SAR; China, Macao SAR; Croatia; Cyprus; Czech Rep.; Denmark; Equatorial Guinea; Estonia; Finland; France; Germany; Greece; Iceland; Ireland; Israel; Italy; Japan; Kuwait; Latvia; Liechtenstein; Lithuania; Luxembourg; Malta; Netherlands; New Zealand; Norway; Oman; Poland; Portugal; Qatar; Korea, Rep. of; Russian Federation; St Kitts and Nevis; Saudi Arabia; Singapore; Slovakia; Slovenia; Spain; Sweden; Switzerland; Trinidad and Tobago; United Arab Emirates; United Kingdom; United States of America; Uruguay

Upper-middle-income economies
Albania; Algeria; Angola; Argentina; Azerbaijan; Belarus; Belize; Bosnia and Herzegovina; Botswana; Brazil; Bulgaria; China; Colombia; Costa Rica; Cuba; Dominica; Dominican Rep.; Ecuador; Fiji; Gabon; Grenada; Hungary; Iran, Islamic Rep. of; Iraq; Jamaica; Jordan; Kazakhstan; Lebanon; Libya; Malaysia; Maldives; Marshall Islands; Mauritius; Mexico; Montenegro; Namibia; Palau; Panama; Peru; Romania; St Lucia; St Vincent and the Grenadines; Serbia; Seychelles; South Africa; Suriname; Thailand; Macedonia, FYR; Tonga; Tunisia; Turkey; Turkmenistan; Tuvalu; Venezuela

Lower-middle-income economies
Armenia; Bhutan; Bolivia; Cabo Verde; Cameroon; Congo; Côte d'Ivoire; Djibouti; Egypt; El Salvador; Georgia; Ghana; Guatemala; Guyana; Honduras; India; Indonesia; Kiribati; Kyrgyzstan; Lao PDR; Lesotho; Mauritania; Micronesia; Mongolia; Morocco; Nicaragua; Nigeria; Pakistan; Palestine; Papua New Guinea; Paraguay; Philippines; Moldova, Rep. of; Samoa; Sao Tome and Principe; Senegal; Solomon Islands; South Sudan; Sri Lanka; Sudan; Swaziland; Syrian Arab Rep.; Timor-Leste; Ukraine; Uzbekistan; Vanuatu; Viet Nam; Yemen; Zambia

Low-income economies
Afghanistan; Bangladesh; Benin; Burkina Faso; Burundi; Cambodia; Central African Rep.; Chad; Comoros; Korea, DPR; Congo, Dem. Rep. of; Eritrea; Ethiopia; Gambia; Guinea; Guinea-Bissau; Haiti; Kenya; Liberia; Madagascar; Malawi; Mali; Mozambique; Myanmar; Nepal; Niger; Rwanda; Sierra Leone; Somalia; Tajikistan; Togo; Uganda; Tanzania; Zimbabwe

1. Grouping by income level are based on '2013 gross national income (GNI) per capita', calculated using the World Bank Atlas method, as of 1 May 2015.

AMERICAS

North America
Canada; United States of America

Latin America
Argentina; Belize; Bolivia; Brazil; Chile; Colombia; Costa Rica; Ecuador; El Salvador; Guatemala; Guyana; Honduras; Mexico; Nicaragua; Panama; Paraguay; Peru; Suriname; Uruguay; Venezuela

Caribbean
Antigua and Barbuda; Bahamas; Barbados; Cuba; Dominica; Dominican Rep.; Grenada; Haiti; Jamaica; St Kitts and Nevis; St Lucia; St Vincent and the Grenadines; Trinidad and Tobago

EUROPE

European Union
Austria; Belgium; Bulgaria; Croatia; Cyprus; Czech Rep.; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; Luxembourg; Malta; Netherlands; Poland; Portugal; Romania; Slovakia; Slovenia; Spain; Sweden; United Kingdom

South-East Europe
Albania; Bosnia and Herzegovina; Montenegro; Serbia; Macedonia, FYR

European Free Trade Association
Iceland; Liechtenstein; Norway; Switzerland

Other Europe
Belarus; Moldova, Rep. of; Russian Federation; Turkey; Ukraine

AFRICA

Sub-Saharan Africa
Angola; Benin; Botswana; Burkina Faso; Burundi; Cameroon; Cabo Verde; Central African Rep.; Chad; Comoros; Congo; Côte d'Ivoire; Congo, Dem. Rep. of; Djibouti; Equatorial Guinea; Eritrea; Ethiopia; Gabon; Gambia; Ghana; Guinea; Guinea-Bissau; Kenya; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritius; Mozambique; Namibia; Niger; Nigeria; Rwanda; Sao Tome and Principe; Senegal; Seychelles; Sierra Leone; Somalia; South Africa; South Sudan; Swaziland; Togo; Uganda; Tanzania; Zambia; Zimbabwe

Arab States in Africa
Algeria; Egypt; Libya; Mauritania; Morocco; Sudan; Tunisia

Annex 1: Composition of regions and sub-regions

ASIA

Central Asia
Kazakhstan; Kyrgyzstan; Mongolia; Tajikistan; Turkmenistan; Uzbekistan

Arab States in Asia
Bahrain; Iraq; Jordan; Kuwait; Lebanon; Oman; Palestine; Qatar; Saudi Arabia; Syrian Arab Rep.; United Arab Emirates; Yemen

West Asia
Armenia; Azerbaijan; Georgia; Iran, Islamic Rep. of; Israel

South Asia
Afghanistan; Bangladesh; Bhutan; India; Maldives; Nepal; Pakistan; Sri Lanka

South-East Asia
Brunei Darussalam; Cambodia; China; China, Hong Kong SAR; China, Macao SAR; Korea, DPR; Indonesia; Japan; Lao PDR; Malaysia; Myanmar; Philippines; Korea, Rep. of; Singapore; Thailand; Timor-Leste; Viet Nam

OCEANIA

Australia; New Zealand; Cook Islands; Fiji; Kiribati; Marshall Islands; Micronesia; Nauru; Niue; Palau; Papua New Guinea; Samoa; Solomon Islands; Tonga; Tuvalu; Vanuatu

Least developed countries[2]
Afghanistan; Angola; Bangladesh; Benin; Bhutan; Burkina Faso; Burundi; Cambodia; Central African Rep.; Chad; Comoros; Congo, Dem. Rep. of; Djibouti; Equatorial Guinea; Eritrea; Ethiopia; Gambia; Guinea; Guinea-Bissau; Haiti; Kiribati; Lao PDR; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritania; Mozambique; Myanmar; Nepal; Niger; Rwanda; Sao Tome and Principe; Senegal; Sierra Leone; Solomon Islands; Somalia; South Sudan; Sudan; Timor-Leste; Togo; Tuvalu; Uganda; Tanzania; Vanuatu; Yemen; Zambia

Arab States
Algeria; Bahrain; Egypt; Iraq; Jordan; Kuwait; Lebanon; Libya; Mauritania; Morocco; Oman; Palestine; Qatar; Saudi Arabia; Sudan; Syrian Arab Rep.; Tunisia; United Arab Emirates; Yemen

2. based on the standard classification of the United Nations Statistics Division, as of May 2015: http://unstats.un.org/unsd/methods/m49/m49regin.htm

OECD

Australia; Austria; Belgium; Canada; Chile; Czech Rep.; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Iceland; Ireland; Israel; Italy; Japan; Luxembourg; Mexico; Netherlands; New Zealand; Norway; Poland; Portugal; Korea, Rep. of; Slovakia; Slovenia; Spain; Sweden; Switzerland; Turkey; United Kingdom; United States of America

G20

Argentina; Australia; Brazil; Canada; China; France; Germany; India; Indonesia; Italy; Japan; Korea, Rep. of; Mexico; Russian Federation; Saudi Arabia; South Africa; Turkey; United Kingdom; United States of America; European Union

Groupings mentioned elsewhere in the report *(in alphabetical order)*

Arab Maghreb Union
Algeria; Libya; Mauritania; Morocco; Tunisia

Common Market for Eastern and Southern Africa (COMESA)
Burundi; Comoros; Democratic Republic of Congo; Djibouti; Egypt; Eritrea; Ethiopia; Kenya; Libya; Seychelles; Swaziland; Madagascar; Malawi; Mauritius; Rwanda; Seychelles; Sudan; Uganda; Zambia; Zimbabwe

Asia–Pacific Economic Cooperation (APEC)
Australia; Brunei Darussalam; Canada; Chile; People's Republic of China; Hong Kong (China); Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; The Philippines; Russian Federation; Singapore; Chinese Taipei; Thailand; United States of America; Viet Nam

Asian Tigers
Chinese Taipei; Hong Kong (China); Indonesia; Malaysia; Philippines; Republic of Korea; Singapore; Thailand; Viet Nam

Association of Southeast Asian Nations (ASEAN)
Brunei Darussalam; Cambodia; Indonesia; Lao PDR; Malaysia; Myanmar; Philippines; Singapore; Thailand; Viet Nam

Caribbean Common Market (CARICOM)
Antigua and Barbuda; Bahamas; Barbados; Belize; Dominica; Dominican Republic; Grenada; Guyana; Haiti; Jamaica; Montserrat; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Suriname; Trinidad and Tobago

Central Asia Regional Economic Cooperation
Afghanistan; Azerbaijan; China; Kazakhstan; Kyrgyzstan; Mongolia; Pakistan Tajikistan; Turkmenistan; Uzbekistan

East African Community
Burundi; Kenya; Rwanda; Tanzania; Uganda

Economic Community of Central African States
Angola; Burundi; Cameroon; Central African Republic; Chad; Republic of Congo; Democratic Republic of Congo; Equatorial Guinea; Gabon; Sao Tomé and Principe

Economic Community of West African States
Benin; Burkina Faso; Cape Verde; Côte d'Ivoire; Gambia; Ghana; Guinea; Guinea-Bissau; Liberia; Mali; Niger; Nigeria; Senegal; Sierra Leone; Togo

Economic Cooperation Organization
Afghanistan; Azerbaijan; Iran; Kazakhstan; Kyrgyzstan; Pakistan; Tajikistan; Turkey; Turkmenistan; Uzbekistan

Economic and Monetary Community of Central Africa
Cameroon; Central African Republic; Chad; Republic of Congo; Equatorial Guinea; Gabon

Eurasian Economic Union
Armenia, Belarus, Kazakhstan, Russian Federation; Kyrgyzstan's accession expected to come into force in May 2015.

Greater Mekong Subregion
Cambodia; People's Republic of China; Lao People's Democratic Republic; Myanmar; Thailand; Viet Nam

Indian Ocean Rim Association for Regional Cooperation
Australia; Bangladesh; India; Indonesia; Iran; Kenya; Madagascar; Malaysia; Mauritius, Mozambique; Oman; Singapore; South Africa; Sri Lanka; Tanzania; Thailand, United Arab Emirates; Yemen

Intergovernmental Authority on Development
Djibouti ; Eritrea; Ethiopia; Kenya; Somalia; South Sudan; Sudan; Uganda

Mercado Commún del Sur (MERCOSUR)
Argentina; Brazil; Paraguay; Uruguay; Venezuela

North Atlantic Treaty Organization
Albania; Bulgaria; Belgium; Canada; Croatia; Czech Republic; Denmark; Estonia; France; Germany; Greece; Hungary; Iceland; Italy; Latvia; Lithuania; Luxembourg; Netherlands; Norway; Poland; Portugal; Romania; Slovakia; Slovenia; Spain; Turkey; UK; USA

Organization of American States
Antigua and Barbuda; Argentina; Bahamas; Barbados; Belize; Bolivia; Brazil; Canada; Chile; Colombia; Costa Rica; Cuba; Dominica; Dominican Republic; Ecuador; El Salvador; Grenada; Guatemala; Guyana; Haiti; Honduras; Jamaica; Mexico; Nicaragua; Panama; Paraguay; Peru; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Suriname; Trinidad and Tobago; United States of America; Uruguay; Venezuela

Organization of the Black Sea Economic Cooperation
Albania; Armenia; Azerbaijan; Bulgaria; Georgia; Greece; Moldova; Romania; Russian Federation; Serbia; Turkey; Ukraine

Organization of the Islamic Conference
Afghanistan; Albania; Algeria; Azerbaijan; Bahrain; Bangladesh; Benin; Brunei Darussalam; Burkina Faso; Cameroon; Chad; Comoros; Côte d'Ivoire; Djibouti; Egypt; Gabon; Gambia; Guinea; Guinea Bissau; Guyana; Indonesia; Iran; Iraq; Kazakhstan; Kuwait; Oman; Jordan; Kazakhstan; Lebanon; Libya; Maldives; Malaysia; Mali; Mauritania; Morocco; Mozambique; Niger; Nigeria; Palestine; Pakistan; Qatar; Saudi Arabia; Senegal; Sierra Leone; Somalia; Sudan; Suriname; Syrian Arab Republic; Tajikistan; Togo; Turkey; Turkmenistan; Tunisia; Uganda; United Arab Emirates; Uzbekistan; Yemen

Organization for Security and Co-operation in Europe
Albania; Andorra; Armenia; Austria; Azerbaijan; Belarus; Belgium; Bosnia and Herzegovina; Bulgaria; Canada; Croatia; Cyprus; Czech Republic; Denmark; Estonia; Finland; France; Georgia; Germany; Greece; Holy See; Hungary; Iceland; Ireland; Italy; Kazakhstan; Kyrgyzstan; Latvia; Liechtenstein; Lithuania; Luxembourg; Malta; Moldova; Monaco; Mongolia; Montenegro; Netherlands; Norway; Poland; Portugal; Romania; Russian Federation; San Marino; Serbia; Slovakia; Spain; Sweden; Slovenia; Switzerland; Tajikistan; Turkey; Turkmenistan; Ukraine; Uzbekistan; United Kingdom of Great Britain and Northern Ireland; United States of America; Former Yugoslav Republic of Macedonia

Pacific Islands Forum
Australia; Cook Islands; Federated States of Micronesia; Fiji; Kiribati; Nauru; New Zealand; Niue; Palau; Papua New Guinea; Republic of Marshall Islands; Samoa; Solomon Islands; Tonga; Tuvalu; Vanuatu

Secretariat of the Pacific Community

American Samoa ; Cook Islands; Federated States of Micronesia; Fiji; French Polynesia; Guam; Kiribati; Marshall Islands; Nauru; New Caledonia; Niue; Northern Mariana Islands ; Palau; Papua New Guinea ; Pitcairn Islands; Samoa; Solomon Islands; Tokelau; Tonga ; Tuvalu; Vanuatu; Wallis and Futuna

Shanghai Cooperation Organisation

China; Kazakhstan; Kyrgyzstan; Russian Federation Tajikistan; Turkmenistan; Uzbekistan

Southern African Development Community

Angola; Botswana; Democratic Republic of the Congo; Lesotho; Madagascar; Malawi; Mauritius; Mozambique; Namibia; Seychelles; South Africa; Swaziland; United Republic of Tanzania; Zambia; Zimbabwe

World Trade Organization

Albania; Andorra; Angola; Antigua and Barbuda; Argentina; Armenia; Australia; Austria; Azerbaijan; Bahrain; Bangladesh; Barbados; Belarus; Belgium; Belize; Benin; Bolivia; Bosnia and Herzegovina; Botswana; Brazil; Brunei Darussalam; Bulgaria; Burkina Faso; Burundi; Canada; Cape Verde; Cambodia; Central African Republic; Chad; Chile; China; Colombia; Republic of Congo; Costa Rica; Côte d'Ivoire; Croatia; Cuba; Cyprus; Czech Republic; Democratic Republic of Congo; Denmark; Djibouti; Dominica; Dominican Republic; Ecuador; Egypt; El Salvador; Estonia; Fiji; Finland; France; Gabon; The Gambia; Georgia; Germany; Ghana; Greece; Grenada; Guatemala; Guinea; Guinea-Bissau; Haiti; Honduras; Hong Kong, China; Holy See; Hungary; Iceland; India; Ireland; Israel; Italy; Jamaica; Japan; Jordan; Kazakhstan; Kenya; Republic of Korea; Kuwait; Kyrgyzstan; Lao People's Democratic Republic; Latvia; Lesotho; Liechtenstein; Lithuania; Luxembourg; Macao, China; Madagascar; Malawi; Malaysia; Maldives; Malta; Mauritania; Mauritius; Mexico; Moldova; Monaco; Mongolia; Montenegro; Morocco; Mozambique; Myanmar; Namibia; Nepal; Netherlands; New Zealand; Nicaragua; Niger; Nigeria; Norway; Oman; Pakistan; Panama; Papua New Guinea; Paraguay; Peru; Philippines; Poland; Portugal; Qatar; Romania; Russian Federation; Rwanda; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Samoa; San Marino; Saudi Arabia; Senegal; Sierra Leone; Singapore; Serbia; Slovakia; Slovenia; Solomon Islands; South Africa; Spain; Sri Lanka; Suriname; Swaziland; Sweden; Switzerland; Chinese Taipei; Tajikistan; United Republic of Tanzania; Thailand; Togo; Tonga; Trinidad and Tobago; Tunisia; Turkey; Turkmenistan; Uganda; Ukraine; United Arab Emirates; United Kingdom of Great Britain and Northern Ireland; United States of America; ; Uruguay; Uzbekistan; Vanuatu; Venezuela; Viet Nam; Yemen; Former Yugoslav Republic of Macedonia; Zambia; Zimbabwe

Annex 2: Glossary

Brownfield investment
Investment in an existing site used for commercial purposes, such as a factory, airport, power plant or steel mill, in order to expand the business or upgrade the facilities and thereby improve the return on investment; see also greenfield investment

Business accelerator
A model which provides start-ups with training, facilities, mentorship and partners; accelerators invest in their start-ups, unlike business incubators (see next entry)

Business incubator
A model which provides start-ups with training, facilities, mentorship and partners; incubators do not invest in their start-ups, unlike business accelerators (see previous entry)

Business sector (*for R&D data*)
All public and private firms, organizations and institutions whose primary activity is the market production of goods or services (other than higher education) for sale to the general public at an economically significant price; includes the private non-profit institutions mainly serving them

Capital expenditure (*for R&D data*)
Annual gross expenditure on fixed assets used in the R&D programmes of statistical units, which should be reported in full for the period when the expenditure occurred and should not be registered as an element of depreciation

Current costs *(for R&D data)*
Composed of labour costs and other current costs; labour costs of R&D personnel consist of annual wages, salaries and all associated costs or fringe benefits; other current costs comprise non-capital purchases of materials, supplies and equipment to support R&D

Disruptive innovation
Dynamic start-ups which may be working on innovation with potential to create new markets and disrupt the business model of their more established competitors, including large corporations; increasingly, corporations are opting to support these start-ups through business accelerators and business incubators (see above), as this approach can be more cost-effective than the acquisition of the new technology; they also stand to gain insights into the future of their market and defuse disruptive innovation; examples of corporations that have invested in disruptive innovation incubators and accelerators are Allianz, Google, LinkedIn, Microsoft, Samsung, Starbucks, Telefonica and Turner

Dutch Disease
Economic term describing the cause and effect relationship between a resource boom and a decline in manufacturing; the term was coined in 1977 by *The Economist* to describe the decline of the manufacturing sector in the Netherlands after the discovery of a large natural gas field in 1959; a resource boom fuels demand for labour, causing production to shift towards the booming sector, such as hydrocarbons or minerals, to the detriment of manufacturing; a secondary effect is the appreciation of the national currency, which causes export-oriented manufacturing to suffer

***Ex post* evaluation**
Assesses the relevance, effectiveness, impact and sustainability of a completed project on the basis of international criteria

Fields of education
According to the International Standard Classification of Education 1997: *Science*: life sciences, physical sciences, mathematics and statistics; computer sciences; *Engineering, Manufacturing and Construction*: engineering and engineering trades; manufacturing and processing; architecture and building; *Agriculture*: agriculture, forestry and fishery; veterinary science. *Health and Welfare*: medicine; medical services; nursing; dental services; social care; social work

Fields of science and technology
According to the OECD's Revised Fields of Science and Technology Classification (2007), these are: natural sciences; engineering and technology; medical and health sciences; agricultural sciences; social sciences and humanities; **natural sciences** include: mathematics; computer and information sciences; physical sciences; chemical sciences; earth and related environmental sciences; and biological sciences; **engineering and technology** include: civil engineering; electrical, electronic, information engineering; mechanical engineering; chemical engineering; materials engineering; medical engineering; environmental engineering; environmental biotechnology; industrial biotechnology; and nanotechnology; **medical and health sciences** include: basic medicine; clinical medicine; health sciences; health biotechnology; and other medical sciences; **agricultural sciences** include: agriculture, forestry and fisheries; animal and dairy science; veterinary sciences; and agricultural biotechnology; **social sciences** include: psychology; economics and business; educational sciences; sociology; law; political science; social and economic geography; media and communications; **humanities** include: history and archaeology; languages and literature; philosophy, ethics and religion; and art

Firms with abandoned or ongoing innovation activities
Firms that did not necessarily implement innovations but had abandoned or ongoing innovation activities to develop them. Unless otherwise specified, the term covers product or process innovation, regardless of organizational or marketing innovation

Full-time equivalence (*for R&D data*)
A measure of the actual volume of human resources devoted to R&D that is especially useful for international comparisons; one full-time equivalent (FTE) may be thought of as a one person-year; a person who normally spends 30% of their time on R&D and the rest on other activities (such as teaching, university administration and student counselling) should be considered as a 0.3 FTE; similarly, if a full-time R&D worker is employed at an R&D unit for only six months, this results in an FTE of 0.5 for that year

Gender parity
Purely a numerical concept; for R&D statistics, gender parity is reached when women represent between 45% and 55% of the total number of researchers

Reaching gender parity in education implies that the same proportion of boys and girls – relative to their respective age groups – would enter the education system and participate in its different cycles

GERD as a percentage of GDP
The total intramural expenditure on R&D performed in the national territory or region during a given year, expressed as a percentage of GDP of the national territory or region.

Gini index
Measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution. A Gini index of zero represents perfect equality and 100 perfect inequality. Relatively equal societies typically have an index close to 30, very unequal ones in the upper 40s and above

Global Competitive Index
A tool developed by the World Economic Forum that ranks countries according to three types of attribute: '*basic requirements*' encompass institutions, infrastructure, macro-economic stability, health and primary education; '*efficiency enhancers*' include higher education and training, labour market efficiency, financial market sophistication, market size and technological readiness; '*innovation and sophistication*' factors cover business sophistication and innovation

Government expenditure on tertiary education as a percentage of GDP
Total general (local, regional and central) government expenditure on tertiary education (current, capital, and transfers), expressed as a percentage of GDP; includes expenditure funded by transfers from international sources to government

Government sector (*for R&D data*)
All departments, offices and other bodies which furnish, but normally do not sell to the community, those common services (other than higher education) that cannot otherwise be conveniently and economically provided, as well as those that administer the state and the community's socio-economic policy; and the non-profit institutions controlled and mainly financed by government but not administered by the higher education sector; public enterprises are included in the business enterprise sector

Greenfield investment
Investment in a factory, airport, power plant, steel mill or other physical commerce-related structure where no facilities existed previously. A parent company may construct new facilities in the same country or a foreign country; governments may offer prospective companies incentives to set up a greenfield investment (tax breaks, subsidies, etc.), as most parent companies tend to create jobs in the foreign country, in addition to infrastructure; see also brownfield investment

Gross domestic expenditure on R&D (GERD)
All expenditure on R&D performed within a statistical unit or sector of the national economy during a specific period, whatever the source of funds

Gross domestic product
The sum of gross value added by all resident producers in the economy, including distributive trades and transport, plus any product taxes and minus any subsidies not included in the value of the products

Gross enrolment ratio
Number of students enrolled in a given level of education, regardless of age, expressed as a percentage of the official school-age population corresponding to the same level of education; for the tertiary level, the population used is the

five-year age group starting from the official secondary school graduation age

Gross fixed capital formation
Consists of investment in land improvements (fences, ditches, drains, etc.); plant, machinery and equipment purchases; and the construction of roads, railways and the like, including commercial and industrial buildings, offices, schools, hospitals and private residences, without taking into account the depreciation of assets.

Head count (*for R&D data*)
Data on the total number of persons who are mainly or partially employed in R&D; this includes staff employed both 'full-time' and 'part-time'; these data allow links to be made with other data series, such as education and employment data, or the results of population censuses; they are also the basis for calculating indicators analysing the characteristics of the R&D labour force with respect to age, gender or national origin

Higher education sector (*for R&D data*)
All universities, colleges of technology and other institutions of post-secondary education, whatever their source of finance or legal status; and all research institutes, experimental stations and clinics operating under the direct control of or administered by or associated with higher education institutions

Innovation
The implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations

Innovation-active firms
Firms that had innovation activities during the observation period, regardless of whether the activity resulted in the implementation of an innovation; unless otherwise specified, the term covers product or process innovation, regardless of organizational or marketing innovation

Innovation activities
All scientific, technological, organizational, financial and commercial steps which actually lead, or are intended to lead, to the implementation of innovation; Some innovation activities are themselves innovative, others are not novel activities but are necessary for the implementation of innovation; also includes R&D that is not directly related to the development of a specific innovation

Innovative firms
Firms that have implemented an innovation; unless otherwise specified, the term is used to refer to product or process innovative firms, which are also known as product or process innovators

Innovation Union Scoreboard
Tool used by the European Union (EU) to monitor each year the performance of Member States and European countries with pre-accession status, via 25 indicators; countries are classified into four categories: innovation leaders (well above the EU average); innovation followers (above or close to the EU average); moderate innovators (below the EU average) and modest innovators (well below the EU average)

Knowledge Economy Index
A composite set of indicators reflecting: the incentives offered by the economic and institutional sectors to make efficient use of existing and new knowledge and nurture entrepreneurship; the population's level of education and skills; an efficient innovation ecosystem comprised of firms, research centres, universities and other organizations; information and communication technologies

Knowledge Index
A composite of indicators reflecting the population's level of education and skills; an efficient innovation ecosystem comprised of firms, research centres, universities and other organizations; information and communication technologies

Marketing innovation
The implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion, or pricing

Organizational innovation
The implementation of a new organizational method in the firm's business practices, workplace organization or external relations

Patent and non-patent citations
The references provided in the search report that are used to assess an invention's patentability and help to define the legitimacy of the claims of a new patent application; as they refer to the prior art, they indicate the knowledge that preceded the invention and may also be cited to show the lack of novelty of the citing invention; however, citations also indicate the legal boundaries of the claims of the patent in question; they therefore serve an important legal function,

since they delimit the scope of the property rights awarded by the patent

Patent family
A set of patents taken in various countries for protecting a single invention; an inventor seeking protection files a first application (priority) generally in their country of residence; the inventor then has a 12-month legal delay for applying or not for protection for the original invention in other countries; patent families, as opposed to patents, are provided with the intention of improving international comparability: the home advantage is suppressed; the values of the patents are homogeneous

Private non-profit sector (*for R&D data*)
Non-market, private non-profit institutions serving households (i.e. the general public); and private individuals or households

Product innovation
The implementation of a good or service that is new or significantly improved with respect to its characteristics or intended uses; includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics

Process innovation
The implementation of a new or significantly improved production or delivery method, including significant changes to a technique, equipment and/or software

Purchasing power parities
A given sum of money, when converted into US dollars at the purchasing power parity rate (PPP$), will buy the same basket of goods and services in all countries; this conversion is used to facilitate international comparisons

Research and experimental development (R&D)
Covers basic research, applied research and experimental development, both formal R&D in R&D units and informal or occasional R&D

R&D personnel
All persons employed directly in R&D, as well as those providing direct services such as R&D managers, administrators and clerical staff; persons providing an indirect service, such as canteen and security staff, are excluded; R&D personnel may be classified by occupation (preferred for international comparisons) or by level of formal qualification

Researchers
Professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems, as well as in the management of the projects concerned

Rule of law
The legal principle that law should govern a nation, as opposed to being governed by arbitrary decisions of individual government officials

Scientific and technological services
Activities concerned with research and experimental development (see earlier entry) that contribute to the generation, dissemination and application of scientific and technical knowledge

Sources of information for innovation
Sources that provide information for new projects involving innovation or contribute to the completion of existing projects; they provide access to knowledge without the need to pay for the knowledge itself, although there may be marginal fees for access, such as membership of trade associations, attendance at conferences, subscriptions to journals

Triadic patent family
A set of patents registered at the European Patent Office, and the Japan Patent Office and granted by the US Patent and Trademark Office which share one or more priorities; triadic patent families are consolidated to eliminate double counting of patents filed at different offices by the same inventor for the same invention


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3: Statistical annex

Table S1: Socio–economic indicators, various years

	Population (000's)	Population growth (annual %)	Life expectancy at birth, total (years)	Unemployment, total (% of total labour force)	GDP in current prices (current PPP$ – millions)		GDP per capita (current PPP$)	
	2014	2014	2013	2013	2007	2013	2007	2013
North America								
Canada	35 525	0.97	81.40	7.10	1 290 073	1 502 939	39 226	42 753
United States of America	322 583	0.79	78.84	7.40	14 477 600	16 768 100	48 061	53 042
Latin America								
Argentina	41 803	0.86	76.19	7.50	–	–	–	–
Belize	340	2.34	73.90	14.60	2 222	2 817	7 763	8 487
Bolivia	10 848	1.64	67.22	2.60	44 218	65 426	4 570	6 131
Brazil	202 034	0.83	73.89	5.90	2 291 377	3 012 934	12 060	15 037
Chile	17 773	0.87	79.84	6.00	277 331	386 614	16 638	21 942
Colombia	48 930	1.25	73.98	10.50	430 916	600 341	9 684	12 424
Costa Rica	4 938	1.34	79.92	7.60	50 798	67 605	11 382	13 876
Ecuador	15 983	1.54	76.47	4.20	118 844	171 385	8 329	10 890
El Salvador	6 384	0.68	72.34	6.30	42 637	49 228	6 963	7 764
Guatemala	15 860	2.50	71.99	2.80	86 653	112 865	6 506	7 297
Guyana	804	0.51	66.21	11.10	3 733	5 234	4 845	6 546
Honduras	8 261	1.99	73.80	4.20	29 065	37 189	4 049	4 593
Mexico	123 799	1.19	77.35	4.90	1 551 985	2 002 543	13 670	16 370
Nicaragua	6 169	1.45	74.79	7.20	21 474	28 230	3 838	4 643
Panama	3 926	1.59	77.58	4.10	43 045	75 028	12 330	19 416
Paraguay	6 918	1.68	72.27	5.20	36 921	55 049	6 028	8 093
Peru	30 769	1.29	74.81	3.90	228 549	357 648	8 068	11 774
Suriname	544	0.86	71.03	7.80	6 280	8 667	12 304	16 071
Uruguay	3 419	0.34	77.05	6.60	44 067	66 759	13 200	19 594
Venezuela	30 851	1.46	74.64	7.50	450 739	553 325	16 298	18 198
Caribbean								
Antigua and Barbuda	91	1.02	75.83	–	2 068	1 892	24 504	21 028
Bahamas	383	1.37	75.07	13.60	8 196	8 779	23 960	23 264
Barbados	286	0.50	75.30	12.20	4 201	4 411^{-1}	15 206	15 574^{-1}
Cuba	11 259	–0.06	79.24	3.20	179 772	211 947^{-2}	15 907	18 796^{-2}
Dominica	72	0.47	76.60^{-11}	–	648	745	9 151	10 343
Dominican Rep.	10 529	1.20	73.45	14.90	92 793	126 784	9 651	12 186
Grenada	106	0.38	72.74	–	1 175	1 233	11 347	11 645
Haiti	10 461	1.39	63.06	7.00	14 405	17 571	1 514	1 703
Jamaica	2 799	0.54	73.47	15.00	22 696	24 141	8 524	8 893
St Kitts and Nevis	55	1.10	71.34^{-11}	–	1 062	1 159	21 036	21 396
St Lucia	184	0.72	74.79	–	1 705	1 912	10 021	10 488
St Vincent and the Grenadines	109	0.00	72.50	–	1 063	1 147	9 749	10 491
Trinidad and Tobago	1 344	0.23	69.93	5.80	37 038	40 833	28 272	30 446
European Union								
Austria	8 526	0.37	80.89	4.90	325 501	382 263	39 238	45 079
Belgium	11 144	0.36	80.39	8.40	389 125	464 923	36 621	41 575
Bulgaria	7 168	–0.76	74.47	12.90	97 975	114 292	12 985	15 732
Croatia	4 272	–0.41	77.13	17.70	83 945	90 861	18 924	21 351
Cyprus	1 153	1.04	79.80	15.80	22 334	24 494	28 488	28 224
Czech Rep.	10 740	0.36	78.28	6.90	274 806	305 101	26 683	29 018
Denmark	5 640	0.37	80.30	7.00	211 218	245 834	38 674	43 782
Estonia	1 284	–0.27	76.42	8.80	29 269	34 035	21 831	25 823
Finland	5 443	0.32	80.83	8.20	198 374	216 146	37 509	39 740
France	64 641	0.54	81.97	10.40	2 178 975	2 474 881	34 040	37 532
Germany	82 652	–0.09	81.04	5.30	3 022 124	3 539 320	36 736	43 884
Greece	11 128	0.00	80.63	27.30	324 007	283 041	29 025	25 667
Hungary	9 933	–0.22	75.27	10.20	193 771	230 867	19 270	23 334
Ireland	4 677	1.08	81.04	13.10	205 290	210 037	46 668	45 684
Italy	61 070	0.13	82.29	12.20	1 971 193	2 125 098	33 731	35 281
Latvia	2 041	–0.45	73.98	11.10	39 032	45 422	17 739	22 569
Lithuania	3 008	–0.29	74.16	11.80	61 649	75 284	19 079	25 454
Luxembourg	537	1.20	81.80	5.90	38 890	49 472	81 023	91 048
Malta	430	0.27	80.75	6.50	9 607	12 332	23 621	29 127
Netherlands	16 802	0.26	81.10	6.70	709 976	775 728	43 340	46 162
Poland	38 221	0.01	76.85	10.40	643 934	912 404	16 892	23 690
Portugal	10 610	0.02	80.37	16.50	265 937	290 756	25 224	27 804
Romania	21 640	–0.27	74.46	7.30	275 071	379 134	13 172	18 974
Slovakia	5 454	0.07	76.26	14.20	115 184	143 437	21 431	26 497
Slovenia	2 076	0.17	80.28	10.20	55 863	59 448	27 681	28 859
Spain	47 066	0.30	82.43	26.60	1 483 742	1 542 768	32 807	33 094
Sweden	9 631	0.63	81.70	8.10	371 092	428 736	40 565	44 658
United Kingdom	63 489	0.56	80.96	7.50	2 294 882	2 452 672	37 423	38 259
South–East Europe								
Albania	3 185	0.38	77.54	16.00	22 748	28 774	7 659	9 931
Bosnia and Herzegovina	3 825	–0.12	76.28	28.40	30 167	36 515	7 798	9 536
Macedonia, FYR	2 108	0.06	75.19	29.00	19 422	24 468	9 264	11 612
Montenegro	622	0.03	74.76	19.80	7 689	8 781	12 446	14 132
Serbia	9 468	–0.44	75.14	22.20	77 164	93 276	10 454	13 020

	GDP growth (annual %)				GDP per economic sector (share of GDP)				Inflation, consumer prices (annual %)	Internet users per 100 inhabitants	Mobile phone subscriptions per 100 inhabitants	Human Development Index (rank)	Global Innovation Index (rank)
					Agriculture	Services	Industry	Manufacturing (subset of industry)					
	2007	2009	2011	2013	2013				2014	2013	2013	2013	2015
	2.01	-2.71	2.53	2.02	1.52^{-3}	70.79^{-3}	27.69^{-3}	10.68^{-3}	1.91	85.80	80.61	8	16
	1.77	-2.80	1.60	2.22	1.31^{-1}	77.71^{-1}	20.98^{-1}	12.96^{-1}	1.62	84.20	95.53	5	5
	8.00	0.05	8.55	2.93	6.98	64.56	28.46	15.27	–	59.90	162.53	49	72
	1.11	0.71	2.10	1.53	15.34	65.55	19.11	11.47	0.65^{-1}	31.70	52.61	84	–
	4.56	3.36	5.17	6.78	13.32	48.56	38.12	13.27	5.78	39.50	97.70	113	104
	6.10	–0.33	2.73	2.49	5.71	69.32	24.98	13.13	6.33	51.60	135.31	79	70
	5.16	-1.04	5.84	4.07	3.44	61.28	35.29	11.48	4.40	66.50	134.29	41	42
	6.90	1.65	6.59	4.68	6.12	56.67	37.21	12.31	2.88	51.70	104.08	98	67
	7.94	-1.02	4.51	3.50	5.64	69.16	25.20	16.06	4.53	45.96	145.97	68	51
	2.19	0.57	7.87	4.64	9.37	51.97	38.66	13.05	3.57	40.35	111.46	98	119
	3.84	-3.13	2.22	1.68	10.84	62.20	26.95	20.17	1.11	23.11	136.19	115	99
	6.30	0.53	4.16	3.69	11.31	59.68	29.01	20.24	3.42	19.70	140.39	125	101
	7.02	3.32	5.44	5.22	21.92	45.30	32.78	3.71	1.83^{-1}	33.00	69.41	121	86
	6.19	-2.43	3.84	2.56	13.39	59.32	27.29	18.81	6.13	17.80	95.92	129	113
	3.15	-4.70	4.04	1.07	3.48	61.71	34.81	17.76	4.02	43.46	85.84	71	57
	5.29	-2.76	5.69	4.61	16.92	52.21	30.87	19.33	6.02	15.50	111.98	132	130
	12.11	3.97	10.77	8.35	3.47^{-1}	74.41^{-1}	22.11^{-1}	5.75^{-1}	2.64	42.90	162.97	65	62
	5.42	-3.97	4.34	14.22	21.59	50.00	28.41	11.63	5.03	36.90	103.69	111	88
	8.52	1.05	6.45	5.79	7.31^{-6}	51.58^{-6}	41.11^{-6}	18.01^{-6}	3.23	39.20	98.08	82	71
	5.11	3.01	5.27	2.88	7.01	44.37	48.62	16.41	3.35	37.40	161.07	100	–
	6.54	2.35	7.34	4.40	9.96	64.65	25.40	12.61	8.88	58.10	154.62	50	68
	8.75	-3.20	4.18	1.34	5.79^{-3}	42.05^{-3}	52.16^{-3}	13.92^{-3}	40.64^{-1}	54.90	101.61	67	132
	9.50	-12.04	-1.79	–0.07	2.28	79.66	18.05	2.95	1.06^{-1}	63.40	127.09	61	–
	1.45	-4.18	1.06	0.67	1.98	79.74	18.28	4.32	1.18	72.00	76.05	51	–
	1.67	-4.14	0.76	0.01^{-1}	1.47^{-1}	82.86^{-1}	15.67^{-1}	6.94^{-1}	1.80^{-1}	75.00	108.10	59	37
	7.26	1.45	2.71	–	5.00^{-2}	74.48^{-2}	20.53^{-2}	10.72^{-2}	–	25.71	17.71	44	–
	6.05	-1.14	–0.08	–0.91	17.17	68.78	14.04	3.47	$–0.05^{-1}$	59.00	129.96	93	–
	8.47	0.94	2.93	4.58	6.32	66.75	26.93	15.92	3.00	45.90	88.43	102	89
	6.12	-6.61	0.76	2.42	5.61	79.19	15.20	3.65	$–0.04^{-1}$	35.00	125.59	79	–
	3.34	3.08	5.52	4.30	–	–	–	–	4.57	10.60	69.40	168	–
	1.40	-4.41	1.70	1.27	6.72^{-1}	72.46^{-1}	20.82^{-1}	9.22^{-1}	8.29	37.80	102.24	96	96
	2.83	-5.60	1.70	4.21	1.68	72.78	25.54	11.01	0.72^{-1}	80.00	142.09	73	–
	–0.47	0.65	1.24	–0.43	3.06	82.56	14.38	3.07	1.47^{-1}	35.20	116.31	97	–
	3.31	-2.10	–0.48	1.66	7.12	75.15	17.73	4.72	0.81^{-1}	52.00	114.63	91	–
	4.75	-4.39	-1.60	1.60	0.62	42.86	56.53	6.38	5.20^{-1}	63.80	144.94	64	80
	3.62	-3.80	3.07	0.23	1.44	70.34	28.22	18.50	1.61	80.62	156.23	21	18
	3.00	-2.62	1.64	0.27	0.83	76.67	22.50	14.22	0.34	82.17	110.90	21	25
	6.91	-5.01	1.98	1.07	5.47	66.60	27.94	–	-1.42	53.06	145.19	58	39
	5.15	-7.38	–0.28	–0.94	4.25	68.57	27.18	13.97	–0.21	66.75	114.51	47	40
	5.13	-1.67	0.40	-5.40	2.08^{-5}	78.33^{-5}	19.59^{-5}	7.56^{-5}	-1.35	65.45	96.36	32	34
	5.53	-4.84	1.96	–0.70	2.61	60.70	36.69	24.89	0.34	74.11	127.73	28	24
	0.82	-5.09	1.15	–0.49	1.36	75.78	22.85	13.73	0.56	94.63	127.12	10	10
	7.90	-14.74	8.28	1.63	3.59	67.46	28.95	15.86	–0.14	80.00	159.66	33	23
	5.18	-8.27	2.57	-1.21	2.68	70.45	26.87	16.62	1.04	91.51	171.57	24	6
	2.36	-2.94	2.08	0.29	1.69	78.49	19.82	11.34	0.51	81.92	98.50	20	21
	3.27	-5.64	3.59	0.11	0.86	68.43	30.71	22.22	0.91	83.96	120.92	6	12
	3.54	-4.39	-8.86	-3.32	3.80	82.41	13.79	8.48	-1.31	59.87	116.82	29	45
	0.51	-6.55	1.81	1.53	4.37	65.41	30.22	22.76	–0.24	72.64	116.43	43	35
	4.93	-6.37	2.77	0.17	1.56	74.34	24.10	19.44	0.20	78.25	102.76	11	8
	1.47	-5.48	0.59	-1.93	2.31	74.42	23.27	14.86	0.24	58.46	158.82	26	31
	9.98	-17.95	5.30	4.11	4.14^{-3}	74.05^{-3}	21.81^{-3}	12.18^{-3}	0.63	75.23	228.40	48	33
	9.84	-14.74	6.00	3.25	3.46^{-3}	68.72^{-3}	27.81^{-3}	–	0.08	68.45	151.34	35	38
	6.46	-5.33	2.61	1.99	0.34	87.47	12.19	5.18	0.63	93.78	148.64	21	9
	4.28	-2.80	1.40	2.90	1.92^{-3}	65.38^{-3}	32.70^{-3}	13.41^{-3}	0.31	68.91	129.75	39	26
	4.20	-3.30	1.66	–0.73	1.97	75.88	22.16	12.11	0.99	93.96	113.73	4	4
	7.20	2.63	4.76	1.67	3.30	63.45	33.25	18.84	0.11	62.85	149.08	35	46
	2.49	-2.98	-1.83	-1.36	2.29	76.65	21.05	12.67	–0.28	62.10	113.04	41	30
	6.26	-6.80	2.31	3.50	6.35	50.40	43.25	–	1.07	49.76	105.58	54	54
	10.68	-5.29	2.70	1.42	4.04	62.73	33.23	20.24	–0.08	77.88	113.91	37	36
	6.94	-7.80	0.61	-1.00	2.14	65.85	32.02	22.32	0.20	72.68	110.21	25	28
	3.77	-3.57	–0.62	-1.23	2.77	73.89	23.34	–	–0.15	71.57	106.89	27	27
	3.40	-5.18	2.66	1.50	1.44	72.71	25.85	16.47	–0.18	94.78	124.40	12	3
	2.56	-4.31	1.65	1.73	0.65	79.16	20.19	9.70	1.46	89.84	124.61	14	2
	5.90	3.35	2.55	1.42	22.24	62.49	15.27	8.94	1.63	60.10	116.16	95	87
	6.84	-2.91	0.96	2.48	8.46	64.43	27.10	13.24	–0.93	67.90	91.10	86	79
	6.15	–0.92	2.80	3.10	10.45	63.38	26.17	11.63	–0.28	61.20	106.17	84	56
	10.66	-5.66	3.23	3.34	9.80	71.36	18.84	5.03	–0.71	56.80	159.95	51	41
	5.89	-3.12	1.40	2.60	8.99^{-1}	60.72^{-1}	30.29^{-1}	18.07^{-1}	2.08	51.50	119.39	77	63

Table S1: Socio–economic indicators, various years

	Population (000's)	Population growth (annual %)	Life expectancy at birth, total (years)	Unemployment, total (% of total labour force)	GDP in current prices (current PPP$ – millions)		GDP per capita (current PPP$)	
	2014	2014	2013	2013	2007	2013	2007	2013
Other Europe and West Asia								
Armenia	2 984	0.25	74.54	16.20	19 373	23 147	6 480	7 776
Azerbaijan	9 515	1.07	70.69	5.50	107 072	161 433	12 477	17 143
Belarus	9 308	−0.53	72.47	5.80	118 019	166 789	12 345	17 620
Georgia	4 323	−0.42	74.08	14.30	23 816	32 128	5 427	7 160
Iran, Islamic Rep. of	78 470	1.31	74.07	13.20	995 290	1 207 413	13 860	15 590
Israel	7 822	1.14	82.06	6.30	195 303	261 858	27 201	32 491
Moldova, Rep. of	3 461	−0.74	68.81	5.10	12 094	16 622	3 381	4 671
Russian Federation	142 468	−0.26	71.07	5.60	2 377 503	3 623 076	16 729	25 248
Turkey	75 837	1.20	75.18	10.00	975 733	1 407 448	14 040	18 783
Ukraine	44 941	−0.66	71.16	7.90	373 877	399 853	8 039	8 790
European Free Trade Assoc.								
Iceland	333	1.09	83.12	5.60	12 147	13 552	38 986	41 859
Liechtenstein	37[-2]	0.99[-2]	82.38	–	–	–	–	–
Norway	5 092	0.97	81.45	3.50	262 828	327 192	55 812	64 406
Switzerland	8 158	0.99	82.75	4.40	357 994	460 605	47 409	56 950
Sub–Saharan Africa								
Angola	22 137	3.05	51.87	6.80	107 683	166 108	6 079	7 736
Benin	10 600	2.64	59.29	1.00	13 255	18 487	1 522	1 791
Botswana	2 039	0.86	47.41	18.40	23 820	31 837	12 437	15 752
Burkina Faso	17 420	2.82	56.28	3.10	17 783	28 526	1 249	1 684
Burundi	10 483	3.10	54.10	6.90	5 593	7 843	672	772
Cabo Verde	504	0.95	74.87	7.00	2 582	3 201	5 338	6 416
Cameroon	22 819	2.51	55.04	4.00	46 126	62 982	2 415	2 830
Central African Rep.	4 709	1.99	50.14	7.60	3 061	2 787	745	604
Chad	13 211	2.96	51.16	7.00	17 680	26 787	1 653	2 089
Comoros	752	2.36	60.86	6.50	847	1 063	1 339	1 446
Congo	4 559	2.46	58.77	6.50	17 372	26 101	4 622	5 868
Congo, Dem. Rep. of	69 360	2.70	49.94	8.00	34 290	54 633	600	809
Côte d'Ivoire	20 805	2.38	50.76	4.00	47 874	65 224	2 667	3 210
Djibouti	886	1.52	61.79	–	1 805	2 618	2 260	2 999
Equatorial Guinea	778	2.74	53.11	8.00	22 192	25 563	34 696	33 768
Eritrea	6 536	3.16	62.75	7.20	6 118	7 572	1 174	1 196
Ethiopia	96 506	2.52	63.62	5.70	65 402	129 859	813	1 380
Gabon	1 711	2.34	63.44	19.60	23 436	32 204	16 192	19 264
Gambia	1 909	3.18	58.83	7.00	2 202	3 072	1 440	1 661
Ghana	26 442	2.05	61.10	4.60	57 529	103 413	2 554	3 992
Guinea	12 044	2.51	56.09	1.80	11 388	14 718	1 133	1 253
Guinea–Bissau	1 746	2.41	54.27	7.10	1 836	2 398	1 237	1 407
Kenya	45 546	2.65	61.68	9.20	85 923	123 968	2 276	2 795
Lesotho	2 098	1.10	49.33	24.70	3 604	5 344	1 843	2 576
Liberia	4 397	2.37	60.53	3.70	1 841	3 770	523	878
Madagascar	23 572	2.78	64.69	3.60	26 784	32 416	1 383	1 414
Malawi	16 829	2.81	55.23	7.60	8 287	12 763	604	780
Mali	15 768	3.00	55.01	8.20	18 892	25 123	1 485	1 642
Mauritius	1 249	0.38	74.46	8.30	16 243	22 296	13 103	17 714
Mozambique	26 473	2.44	50.17	8.30	17 459	28 548	787	1 105
Namibia	2 348	1.92	64.34	16.90	15 868	22 073	7 626	9 583
Niger	18 535	3.87	58.44	5.10	10 683	16 337	752	916
Nigeria	178 517	2.78	52.50	7.50	627 891	972 664	4 266	5 602
Rwanda	12 100	2.71	63.99	0.60	10 164	17 354	1 024	1 474
Sao Tome and Principe	198	2.50	66.26	–	388	573	2 378	2 971
Senegal	14 548	2.89	63.35	10.30	24 042	31 687	2 019	2 242
Seychelles	93	0.50	74.23	–	1 670	2 193	19 636	24 587
Sierra Leone	6 205	1.84	45.55	3.20	6 376	9 407	1 177	1 544
Somalia	10 806	2.91	55.02	6.90	–	–	–	–
South Africa	53 140	0.69	56.74	24.90	552 487	683 974	11 355	12 867
South Sudan	11 739	3.84	55.24	–	–	22 928	–	2 030
Swaziland	1 268	1.45	48.94	22.50	6 933	8 353	6 108	6 685
Tanzania	50 757	3.01	61.49	3.50	73 946	116 832	1 852	2 443
Togo	6 993	2.55	56.49	6.90	6 727	9 479	1 153	1 391
Uganda	38 845	3.31	59.19	3.80	39 569	62 918	1 288	1 674
Zambia	15 021	3.26	58.09	13.30	33 098	57 071	2 733	3 925
Zimbabwe	14 599	3.13	59.77	5.40	18 817	25 923	1 477	1 832
Arab States								
Algeria	39 929	1.82	71.01	9.80	406 365	522 262	11 578	13 320
Bahrain	1 344	0.89	76.67	7.40	42 068	58 417	40 750	43 851
Egypt	83 387	1.61	71.13	12.70	662 430	909 941	8 924	11 089
Iraq	34 769	2.93	69.47	16.00	302 127	499 627	10 512	14 951
Jordan	7 505	3.13	73.90	12.60	55 395	76 116	9 785	11 783
Kuwait	3 479	3.24	74.46	3.10	227 278	272 521[-1]	88 957	83 840[-1]
Lebanon	4 966	2.94	80.13	6.50	51 183	76 722	12 364	17 174
Libya	6 253	0.83	75.36	19.60	154 764	130 519	26 766	21 046

	GDP growth (annual %)				GDP per economic sector (share of GDP)				Inflation, consumer prices (annual %)	Internet users per 100 inhabitants	Mobile phone subscriptions per 100 inhabitants	Human Development Index (rank)	Global Innovation Index (rank)
					Agriculture	Services	Industry	Manufacturing (subset of industry)					
	2007	2009	2011	2013	2013				2014	2013	2013	2013	2015
	13.75	-14.15	4.70	3.50	21.94	46.58	31.48	11.41	2.98	46.30	112.42	87	61
	25.05	9.41	0.07	5.80	5.66	32.27	62.07	4.52	2.42^{-1}	58.70	107.61	76	93
	8.60	0.20	5.54	0.89	9.11	48.65	42.24	26.84	18.12	54.17	118.79	53	53
	12.34	-3.78	7.20	3.32	9.41	66.57	24.02	13.40	3.07	43.10	115.03	79	73
	7.82	3.94	3.00	-5.80	10.22^{-6}	45.31^{-6}	44.47^{-6}	10.55^{-6}	17.24	31.40	84.25	75	106
	6.27	1.90	4.19	3.25	–	–	–	–	0.48	70.80	122.85	19	22
	3.00	-6.00	6.80	8.90	15.04	68.39	16.57	13.64	5.09	48.80	106.01	114	44
	8.54	-7.82	4.26	1.32	3.95	59.78	36.27	14.82	7.83	61.40	152.84	57	48
	4.67	-4.83	8.77	4.12	8.49	64.44	27.07	17.63	8.85	46.25	92.96	69	58
	7.90	-14.80	5.20	1.88	10.43	62.64	26.94	13.71	12.21	41.80	138.06	83	64
	9.72	-5.15	2.13	3.46	7.73^{-1}	67.81^{-1}	24.47^{-1}	13.48^{-1}	2.03	96.55	108.11	13	13
	3.33	-1.16	–	–	–	–	–	–	–	93.80	104.07	18	–
	2.65	-1.63	1.34	0.65	1.55	57.66	40.79	7.29	2.03	95.05	116.27	1	20
	4.14	-2.13	1.80	1.92	0.71	73.56	25.73	18.69	–0.01	86.70	136.78	3	1
	22.59	2.41	3.92	6.80	10.06	32.14	57.80	7.21	7.28	19.10	61.87	149	120
	4.63	2.66	3.26	5.64	36.52	49.46	14.01	8.17	-1.10	4.90	93.26	165	–
	8.68	-7.84	6.18	5.83	2.54	60.54	36.92	5.68	4.40	15.00	160.64	109	90
	4.11	2.87	6.63	6.65	22.87	47.76	29.38	6.42	–0.26	4.40	66.38	181	102
	4.79	3.47	4.19	4.59	39.83	42.44	17.73	9.46	4.38	1.30	24.96	180	136
	15.17	-1.27	3.97	0.54	8.10^{-1}	74.87^{-1}	17.03^{-1}	–	–0.24	37.50	100.11	123	103
	3.26	1.93	4.14	5.56	22.89	47.24	29.87	14.39	1.95^{-1}	6.40	70.39	152	110
	8.12	8.91	3.30	-36.00	54.32^{-1}	31.95^{-1}	13.73^{-1}	6.48^{-1}	1.50^{-1}	3.50	29.47	185	–
	3.27	4.22	0.08	3.97	51.50	33.09	15.41	2.70	0.15^{-1}	2.30	35.56	184	–
	0.80	1.95	2.60	3.50	37.08	50.40	12.52	7.02	2.30^{-1}	6.50	47.28	159	–
	-1.58	7.47	3.42	3.44	4.36	23.62	72.02	4.30	5.97^{-1}	6.60	104.77	140	–
	6.26	2.86	6.87	8.48	20.79	40.97	38.24	16.55	1.63^{-1}	2.20	41.82	186	–
	1.77	3.25	-4.39	8.70	22.28	55.45	22.27	12.75	0.46	2.60	95.45	171	116
	5.10	5.00	5.39	5.00	3.86^{-6}	79.26^{-6}	16.89^{-6}	2.45^{-6}	2.42^{-1}	9.50	27.97	170	–
	13.14	-8.07	5.00	-4.84	–	6.44	–	–	6.35^{-1}	16.40	67.47	144	–
	1.43	3.88	8.68	1.33	14.53^{-4}	63.03^{-4}	22.44^{-4}	5.65^{-4}	–	0.90	5.60	182	–
	11.46	8.80	11.18	10.49	45.03	43.02	11.95	4.04	7.39	1.90	27.25	173	127
	5.55	-2.90	7.10	5.89	4.02^{-1}	31.96^{-1}	64.02^{-1}	–	0.48^{-1}	9.20	214.75	112	–
	3.63	6.45	-4.33	4.80	–	–	–	–	5.95	14.00	99.98	172	112
	6.46	3.99	15.01	7.59	21.86	49.61	28.53	5.78	15.49	12.30	108.19	138	108
	1.76	–0.28	3.91	2.30	20.24	42.09	37.67	6.48	11.89^{-1}	1.60	63.32	179	139
	3.20	3.31	9.03	0.33	43.68	42.65	13.67	–	-1.02	3.10	74.09	177	–
	6.99	3.31	6.12	5.74	29.51	50.67	19.81	11.72	6.88	39.00	71.76	147	92
	4.73	3.36	2.84	5.49	8.30^{-1}	59.88^{-1}	31.82^{-1}	11.65^{-1}	5.34	5.00	86.30	162	118
	15.69	13.76	9.13	11.31	38.84^{-1}	44.75^{-1}	16.41^{-1}	3.32^{-1}	7.57^{-1}	4.60	59.40	175	–
	6.24	-4.01	1.45	2.41	26.37	57.48	16.15	–	6.08	2.20	36.91	155	125
	9.49	9.04	4.35	4.97	26.96	54.25	18.79	10.74	24.43	5.40	32.33	174	98
	4.30	4.46	2.73	2.15	42.26^{-1}	35.01^{-1}	22.73^{-1}	–	0.89	2.30	129.07	176	105
	5.90	3.00	3.90	3.20	3.22	72.49	24.29	17.04	3.22	39.00	123.24	63	49
	7.28	6.48	7.44	7.44	28.99	50.22	20.79	10.86	4.26^{-1}	5.40	48.00	178	95
	6.62	0.30	5.12	5.12	6.14	60.49	33.36	13.16	5.35	13.90	118.43	127	107
	3.15	–0.71	2.31	4.10	37.20	43.36	19.44	6.11	–0.92	1.70	39.29	187	134
	6.83	6.93	4.89	5.39	21.00	57.01	21.99	9.03	8.06	38.00	73.29	152	128
	7.61	6.27	7.85	4.68	33.39	51.73	14.88	5.20	1.27	8.70	56.80	151	94
	2.00	4.02	4.94	4.00	19.78^{-2}	64.29^{-2}	15.93^{-2}	6.41^{-2}	6.43	23.00	64.94	142	–
	4.94	2.42	2.07	2.80	17.52	58.44	24.03	13.56	-1.08	20.90	92.93	163	84
	10.06	-1.11	7.92	5.28	2.37	86.28	11.34	6.27	1.39	50.40	147.34	71	65
	8.04	3.15	5.77	5.52	59.47	32.57	7.96	2.04	7.33	1.70	65.66	183	–
	–	–	–	–	–	–	–	–	–	1.50	49.38	–	–
	5.36	-1.54	3.21	2.21	2.32	67.79	29.90	13.23	5.56	48.90	145.64	118	60
	–	5.04	-4.64	13.13	–	–	–	–	47.28^{-3}	–	25.26	–	–
	3.50	1.25	–0.66	2.78	7.48^{-2}	44.83^{-2}	47.69^{-2}	43.83^{-2}	5.62^{-1}	24.70	71.47	148	123
	7.15	5.40	7.92	7.28	33.85	42.97	23.18	7.36	6.13	4.40	55.72	159	117
	2.29	3.51	4.88	5.12	30.76^{-2}	53.70^{-2}	15.54^{-2}	8.09^{-2}	0.01	4.50	62.53	166	140
	8.41	7.25	9.67	3.27	25.26	53.98	20.76	10.01	4.29	16.20	44.09	164	111
	8.35	9.22	6.34	6.71	9.64	56.50	33.85	8.18	7.81	15.40	71.50	141	124
	-3.65	5.98	11.91	4.48	12.00	56.90	31.10	12.82	1.63^{-1}	18.50	96.35	156	133
	3.40	1.60	2.80	2.80	10.54	41.85	47.61	–	2.92	16.50	100.79	93	126
	8.29	2.54	2.10	5.34	–	–	–	–	2.77	90.00	165.91	44	59
	7.09	4.67	1.76	2.10	14.51	46.32	39.17	15.65	10.20	49.56	121.51	110	100
	1.38	5.81	10.21	4.21	–	–	–	–	1.88^{-1}	9.20	96.10	120	–
	8.18	5.48	2.56	2.83	3.40	66.91	29.69	19.42	2.81	44.20	141.80	77	75
	5.99	-7.08	10.21	8.31^{-1}	0.35	26.34	73.31	6.77	2.53	75.46	190.29	46	77
	9.40	10.30	2.00	0.90	7.18	73.07	19.76	8.63	3.99^{-4}	70.50	80.56	65	74
	6.00	2.10	-62.08	-10.88	1.87^{-5}	19.94^{-5}	78.20^{-5}	4.49^{-5}	2.61^{-1}	16.50	165.04	55	–

Table S1: Socio–economic indicators, various years

	Population (000's)	Population growth (annual %)	Life expectancy at birth, total (years)	Unemployment, total (% of total labour force)	GDP in current prices (current PPP$ – millions)		GDP per capita (current PPP$)	
	2014	2014	2013	2013	2007	2013	2007	2013
Mauritania	3 984	2.40	61.51	31.00	8 523	11 836	2 560	3 043
Morocco	33 493	1.46	70.87	9.20	170 875	241 682	5 489	7 198
Oman	3 926	7.78	76.85	7.90	108 310	150 236[-1]	42 148	45 334[-1]
Palestine	4 436	2.51	73.20	23.40	13 218	19 916[-1]	3 782	4 921[-1]
Qatar	2 268	4.47	78.61	0.50	138 537	296 517	120 210	136 727
Saudi Arabia	29 369	1.86	75.70	5.70	999 859	1 546 500	38 581	53 644
Sudan	38 764	2.08	62.04	15.20	129 873	128 053	3 096	3 373
Syrian Arab Rep.	21 987	0.40	74.72	10.80	–	–	–	–
Tunisia	11 117	1.09	73.65	13.30	92 335	121 107	9 030	11 124
United Arab Emirates	9 446	1.06	77.13	3.80	453 316	550 915[-1]	78 194	59 845[-1]
Yemen	24 969	2.27	63.09	17.40	86 896	96 636	4 102	3 959
Central Asia								
Kazakhstan	16 607	1.01	70.45	5.20	268 714	395 463	17 354	23 214
Kyrgyzstan	5 625	1.39	70.20	8.00	12 902	18 376	2 449	3 213
Mongolia	2 881	1.48	67.55	4.90	14 472	26 787	5 577	9 435
Tajikistan	8 409	2.42	67.37	10.70	12 714	20 620	1 788	2 512
Turkmenistan	5 307	1.27	65.46	10.60	35 860	73 383	7 381	14 004
Uzbekistan	29 325	1.34	68.23	10.70	88 095	156 295	3 279	5 168
South Asia								
Afghanistan	31 281	2.36	60.93	8.00	32 219	59 459	1 223	1 946
Bangladesh	158 513	1.22	70.69	4.30	297 842	461 644	2 034	2 948
Bhutan	766	1.53	68.30	2.10	3 525	5 583	5 189	7 405
India	1 267 402	1.21	66.46	3.60	4 156 058	6 783 778	3 586	5 418
Maldives	352	1.88	77.94	11.60	2 832	4 022	9 186	11 657
Nepal	28 121	1.16	68.40	2.70	43 493	62 400	1 676	2 245
Pakistan	185 133	1.63	66.59	5.10	647 797	838 164	3 952	4 602
Sri Lanka	21 446	0.81	74.24	4.20	124 345	199 466	6 205	9 738
South–East Asia								
Brunei Darussalam	423	1.29	78.57	3.80	26 973	29 987	70 714	71 777
Cambodia	15 408	1.79	71.75	0.30	30 059	46 027	2 187	3 041
China	1 393 784	0.59	75.35	4.60	8 796 899	16 161 655	6 675	11 907
China, Hong Kong SAR	7 260	0.77	83.83	3.30	299 425	382 490	43 293	53 216
China, Macao SAR	575	1.59	80.34	1.80	37 088	80 765	75 197	142 599
Indonesia	252 812	1.17	70.82	6.30	1 544 770	2 388 997	6 688	9 561
Japan	127 000	–0.11	83.33	4.00	4 264 207	4 612 630	33 314	36 223
Korea, DPR	25 027	0.53	69.81	4.60	–	–	–	–
Korea, Rep. of	49 512	0.50	81.46	3.10	1 354 518	1 660 385	27 872	33 062
Lao PDR	6 894	1.82	68.25	1.40	18 685	32 644	3 107	4 822
Malaysia	30 188	1.57	75.02	3.20	489 960	693 535	18 273	23 338
Myanmar	53 719	0.86	65.10	3.40	–	–	–	–
Philippines	100 096	1.72	68.71	7.10	435 875	643 088	4 904	6 536
Singapore	5 517	1.93	82.35	2.80	294 619	425 259	64 207	78 763
Thailand	67 223	0.32	74.37	0.70	743 320	964 518	11 249	14 394
Timor–Leste	1 152	1.71	67.52	4.40	1 266	2 386[-1]	1 246	2 076[-1]
Viet Nam	92 548	0.94	75.76	2.00	310 033	474 958	3 681	5 294
Oceania								
Australia	23 630	1.22	82.20	5.70	761 369	999 241	36 556	43 202
New Zealand	4 551	1.01	81.41	6.20	121 926	154 281	28 866	34 732
Cook Islands	16	0.27	–	–	–	–	–	–
Fiji	887	0.67	69.92	8.10	5 610	6 829	6 716	7 750
Kiribati	104	1.54	68.85	–	157	190	1 679	1 856
Marshall Islands	53	0.26	65.24[-13]	–	170	205	3 255	3 901
Micronesia	104	0.34	68.96	–	323	352	3 073	3 395
Nauru	11	1.91	–	–	–	–	–	–
Niue	1	-2.12	–	–	–	–	–	–
Palau	21	0.63	69.13[-8]	–	298	316	14 811	15 096
Papua New Guinea	7 476	2.09	62.43	2.10	11 472	19 349	1 793	2 643
Samoa	192	0.76	73.26	–	983	1 098	5 393	5 769
Solomon Islands	573	2.05	67.72	3.80	805	1 161	1 637	2 069
Tonga	106	0.43	72.64	–	454	559	4 438	5 304
Tuvalu	11	0.53	–	–	30	36	3 044	3 645
Vanuatu	258	2.17	71.69	–	587	756	2 670	2 991

Source:
Population: United Nations, Department of Economic and Social Affairs, Population Division, 2013; World Population Prospects: The 2012 Revision
Human Development Index (rank): Human Development Report 2014: Sustaining Human Progress: Reducing Vulnerabilities and Building Resilience, Human Development Report Office (HDRO), United Nations Development Programme (UNDP)
Global Innovation Index (rank): Cornell University, INSEAD, and WIPO (2015): The Global Innovation Index 2015: Effective Innovation Policies for Development, Fontainebleau, Ithaca, and Geneva. GDP related data and all the other data not specified under above sources: World Bank; World Development Indicators, as of April 2015

GDP growth (annual %)				GDP per economic sector (share of GDP)				Inflation, consumer prices (annual %)	Internet users per 100 inhabitants	Mobile phone subscriptions per 100 inhabitants	Human Development Index (rank)	Global Innovation Index (rank)
				Agriculture	Services	Industry	Manufact–uring (subset of industry)					
2007	2009	2011	2013	2013				2014	2013	2013	2013	2015
1.02	-1.22	3.99	6.72	15.46	43.02	41.53	4.14	4.13^{-1}	6.20	102.53	161	–
2.71	4.76	4.99	4.38	16.57	54.90	28.53	15.44	0.44	56.00	128.53	129	78
4.45	6.11	0.88	5.76^{-1}	1.27	31.39	67.34	10.67	1.01	66.45	154.65	56	69
-1.77	20.94	7.89	-4.43	5.33^{-1}	69.60^{-1}	25.07^{-1}	16.24^{-1}	2.75^{-5}	46.60	73.74	107	–
17.99	11.96	13.02	6.32	0.09	30.28	69.62	9.94	2.99	85.30	152.64	31	50
5.99	1.83	8.57	3.95	1.84	37.59	60.57	10.09	2.67	60.50	184.20	34	43
11.52	3.23	-3.29	-6.00	28.15	50.17	21.68	8.19	29.96^{-1}	22.70	72.85	166	141
5.70	–	–	–	17.94^{-6}	49.09^{-6}	32.97^{-6}	–	36.70^{-2}	26.20	56.13	118	–
6.23	3.61	–0.51	2.52	8.61	61.41	29.98	16.97	4.94	43.80	115.60	90	76
3.18	-5.24	4.89	5.20	0.66	40.33	59.02	8.53	2.34	88.00	171.87	40	47
3.34	4.13	-15.09	4.16	10.15^{-7}	40.61^{-7}	49.25^{-7}	7.76^{-7}	10.97^{-1}	20.00	69.01	154	137
8.90	1.20	7.50	6.00	4.93	58.18	36.89	11.64	6.72	54.00	184.69	70	82
8.54	2.89	5.96	10.53	17.73	55.59	26.67	15.59	7.53	23.40	121.45	125	109
10.25	-1.27	17.51	11.74	16.47	50.26	33.27	7.17	13.02	17.70	124.18	103	66
7.80	3.80	7.40	7.40	27.41	50.84	21.75	11.19	6.10	16.00	91.83	133	114
11.06	6.10	14.70	10.20	14.55^{-1}	37.01^{-1}	48.44^{-1}	–	–	9.60	116.89	103	–
9.50	8.10	8.30	8.00	19.14	54.59	26.27	10.51	–	38.20	74.31	116	122
13.74	21.02	6.11	1.93	23.97	54.84	21.19	12.10	4.62	5.90	70.66	169	–
7.06	5.05	6.46	6.01	16.28	56.09	27.64	17.27	6.99	6.50	74.43	142	129
17.93	6.66	7.89	2.04	17.08	38.27	44.65	8.98	8.21	29.90	72.20	136	121
9.80	8.48	6.64	6.90	17.95	51.31	30.73	17.26	6.35	15.10	70.78	135	81
10.56	-3.64	6.48	3.71	4.20^{-1}	73.28^{-1}	22.52^{-1}	7.08^{-1}	2.12	44.10	181.19	103	–
3.41	4.53	3.42	3.78	35.10	49.19	15.71	6.59	8.37	13.30	76.85	145	135
4.83	2.83	2.75	4.41	25.11	53.81	21.08	14.01	7.19	10.90	70.13	146	131
6.80	3.54	8.25	7.25	10.76	56.78	32.46	17.71	3.28	21.90	95.50	73	85
0.15	-1.76	3.43	-1.75	0.73	31.03	68.24	12.35	–0.19	64.50	112.21	30	–
10.21	0.09	7.07	7.41	33.52	40.83	25.65	16.44	3.86	6.00	133.89	136	91
14.16	9.21	9.30	7.67	10.01	46.09	43.89	31.83	1.99	45.80	88.71	91	29
6.46	-2.46	4.79	2.93	0.06	92.74	7.20	1.46	4.43	74.20	237.35	15	11
14.33	1.71	21.29	11.89	0.00^{-1}	93.76^{-1}	6.24^{-1}	0.71^{-1}	6.04	65.80	304.08	–	–
6.35	4.63	6.49	5.78	14.43	39.87	45.69	23.70	6.39	15.82	125.36	108	97
2.19	-5.53	–0.45	1.61	1.22^{-1}	73.18^{-1}	25.60^{-1}	18.17^{-1}	2.74	86.25	117.63	17	19
–	–	–	–	–	–	–	–	–	0.00^{-1}	9.72	–	–
5.46	0.71	3.68	2.97	2.34	59.11	38.55	31.10	1.27	84.77	111.00	15	14
7.60	7.50	8.04	8.52	26.51	40.43	33.06	8.25	6.36^{-1}	12.50	68.14	139	–
6.30	-1.51	5.19	4.73	9.31	50.18	40.51	23.92	3.14	66.97	144.69	62	32
13.64^{-3}	–	–	–	48.35^{-9}	35.44^{-9}	16.21^{-9}	11.57^{-9}	5.52^{-1}	1.20	12.83	150	138
6.62	1.15	3.66	7.18	11.23	57.65	31.12	20.40	4.13	37.00	104.50	117	83
9.11	–0.60	6.06	3.85	0.03	74.86	25.11	18.76	1.04	73.00	155.92	9	7
5.04	-2.33	0.08	1.77	11.98	45.47	42.55	32.94	1.90	28.94	140.05	89	55
11.45	12.96	14.67	7.84^{-1}	18.42^{-1}	61.83^{-1}	19.75^{-1}	0.86^{-1}	0.44	1.10	57.38	128	–
7.13	5.40	6.24	5.42	18.38	43.31	38.31	17.49	4.09	43.90	130.89	121	52
3.76	1.73	2.32	2.51	2.45	70.73	26.82	7.13	2.49	83.00	106.84	2	17
3.54	2.21	2.33	2.50	7.18^{-3}	69.07^{-3}	23.75^{-3}	12.18^{-3}	0.84	82.78	105.78	7	15
–	–	–	–	–	–	–	–	–	–	–	–	–
–0.85	-1.39	2.71	3.47	12.22	67.63	20.15	14.50	0.54	37.10	105.60	88	115
7.52	–0.67	2.74	2.97	25.28^{-3}	66.51^{-3}	8.21^{-3}	5.55^{-3}	–	11.50	16.61	133	–
3.77	-1.66	0.02	2.99	–	–	–	–	–	11.70	1.27^{-8}	–	–
-2.06	0.96	2.05	-4.00	28.21^{-2}	62.65^{-2}	9.22^{-2}	0.49^{-2}	–	27.80	30.32	124	–
–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–
1.85	-10.75	5.33	–0.33	5.33	86.42	8.25	1.11	–	26.97^{-9}	85.79	60	–
7.15	6.14	10.67	5.54	37.80^{-9}	23.33^{-9}	38.87^{-9}	7.05^{-9}	4.96^{-1}	6.50	40.98	157	–
6.32	-4.81	5.15	-1.14	–	–	–	–	–0.41	15.30	47.19^{-6}	106	–
7.32	-4.73	10.70	2.95	35.65^{-7}	57.59^{-7}	6.75^{-7}	4.85^{-7}	5.39^{-1}	8.00	57.57	157	–
-4.14	3.24	2.88	0.50	19.17^{-1}	59.34^{-1}	21.49^{-1}	6.43^{-1}	2.51	35.00	54.59	100	–
6.35	-4.43	8.45	1.30	22.16	69.11	8.73	–	–	37.00	34.43	–	–
5.18	3.31	1.21	1.97	27.98	63.22	8.80	3.61	0.80	11.30	50.34	131	–

Abbreviations:
GDP: gross domestic product
PPP$: purchasing power parity dollars

NB: See Key To All Tables at the end of Table S10.

Table S2: R&D expenditure by sector of performance and source of funds, 2009 and 2013 (%)

	R&D expenditure by sector of performance (%)									
	2009					2013				
	Business enterprise	Government	Higher education	Private non–profit	Not elsewhere classified	Business enterprise	Government	Higher education	Private non–profit	Not elsewhere classified
North America										
Canada	53.23	10.45	35.91	0.41	–	50.52	9.15[v]	39.80[v]	0.52	–
United States of America	69.55[o]	11.93	14.03[o]	4.48[o,r]	–	69.83[-1,o,v]	12.31[-1,v]	13.83[-1,o,v]	4.03[-1,o,r]	–[-1]
Latin America										
Argentina	22.26	44.73	31.32	1.69	–	21.47[-1]	45.59[-1]	31.17[-1]	1.76[-1]	–[-1]
Belize	–	–	–	–	–	–	–	–	–	–
Bolivia	25.00[-7]	21.00[-7]	41.00[-7]	13.00[-7]	–[-7]	–	–	–	–	–
Brazil	–	–	–	–	–	–	–	–	–	–
Chile	29.32	3.34	39.81	27.53	–	34.43[-1]	4.08[-1]	34.27[-1]	27.23[-1]	–[-1]
Colombia	19.77	4.62	49.83	25.79	–	23.12	7.57	42.32	26.99	–
Costa Rica	25.71	23.49	48.99	1.82	–	15.85[-2]	36.59[-2]	45.23[-2]	2.32[-2]	0.02[-2]
Ecuador	40.85	42.04	12.97	4.14	–	58.12[-2]	24.52[-2]	14.19[-2]	3.17[-2]	–[-2]
El Salvador	–	–	100.00	–	–	–[-1]	–[-1]	100.00[-1]	–[-1]	–[-1]
Guatemala	2.00[q]	11.16[q]	84.67[q]	2.17[q]	–	0.17[-1,q]	16.54[-1,q]	82.32[-1,q]	0.96[-1,q]	–[-1]
Guyana	–	–	–	–	–	–	–	–	–	–
Honduras	–	–	–	–	–	–	–	–	–	–
Mexico	41.07	26.81	29.21	2.91	–	37.97	31.39	29.10	1.55	–
Nicaragua	–	–	–	–	–	–	–	–	–	–
Panama	1.75	51.71	2.44	44.08	0.01	2.00[-2]	64.30[-2]	2.46[-2]	31.30[-2]	–[-2]
Paraguay	–[-1]	28.32[-1]	59.86[-1]	11.82[-1]	0.00[-1]	–[-1]	31.62[-1]	59.92[-1]	8.46[-1]	–[-1]
Peru	29.17[-5]	25.63[-5]	38.11[-5]	7.08[-5]	0.00[-5]	–	–	–	–	–
Suriname	–	–	–	–	–	–	–	–	–	–
Uruguay	34.44	27.12	34.60	2.73	1.11	17.99[-1]	34.01[-1]	43.44[-1]	4.56[-1]	–[-1]
Venezuela	–	–	–	–	–	–	–	–	–	–
Caribbean										
Antigua and Barbuda	–	–	–	–	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–	–	–	–	–
Barbados	–	–	–	–	–	–	–	–	–	–
Cuba	–	–	–	–	–	–	–	–	–	–
Dominica	–	–	–	–	–	–	–	–	–	–
Dominican Rep.	–	–	–	–	–	–	–	–	–	–
Grenada	–	–	–	–	–	–	–	–	–	–
Haiti	–	–	–	–	–	–	–	–	–	–
Jamaica	–	–	–	–	–	–	–	–	–	–
St Kitts and Nevis	–	–	–	–	–	–	–	–	–	–
St Lucia	–	–	–	–	–	–	–	–	–	–
St Vincent and the Grenadines	86.67[-7]	13.33[-7]	–[-7]	–[-7]	–[-7]	–	–	–	–	–
Trinidad and Tobago	2.18	61.27	36.54	–	–	–[-1]	63.29[-1]	36.69[-1]	–[-1]	0.01[-1]
European Union										
Austria	68.09	5.34	26.10	0.48	–	68.78[r,v]	5.14[r,v]	25.59[r,v]	0.49[r,v]	–
Belgium	66.26	8.94	23.79	1.00	–	69.10[v]	8.80[v]	21.68[v]	0.43[v]	–
Bulgaria	29.96	55.24	14.04	0.76	–	61.08	29.67	8.65	0.60	–
Croatia	40.42	27.16	32.31	0.12	–	50.10	25.53	24.36	–	–
Cyprus	19.80	20.42	46.12	13.66	–	15.45[v]	14.40[v]	57.26[v]	12.89[v]	–
Czech Rep.	56.50	23.26	19.70	0.54	–	54.12	18.31	27.23	0.34	–
Denmark	69.78	2.07	27.72	0.42	–	65.43[r,v]	2.39[r,v]	31.77[r,v]	0.40[r,v]	–
Estonia	44.69	10.99	42.16	2.17	–	47.72	8.93	42.30	1.06	–
Finland	71.42	9.10	18.90	0.58	–	68.86	8.92	21.52	0.71	–
France	61.69	16.31	20.80	1.20	–	64.75[v]	13.15[s,v]	20.75[v]	1.35[v]	–
Germany	67.56	14.82[c]	17.62	–[g]	–	66.91[r,v]	15.09[c,r,v]	18.00[r,v]	–[g]	–
Greece	28.59[-2]	20.92[-2,r]	49.23[-2,r]	1.26[-2,r]	–[-2]	33.34[s]	27.98[s]	37.43[s]	1.25	–
Hungary	57.24[t]	20.06[t]	20.94[t]	–	–	69.43[t]	14.89[t]	14.39[t]	–	–
Ireland	68.30	5.05	26.65[r]	–	–	72.03[-1,r]	4.85[-1]	23.12[-1,r]	–[-1]	–[-1]
Italy	53.30	13.14	30.26	3.30	–	53.98[v]	14.92[v]	28.21[v]	2.88[v]	–
Latvia	36.39	24.71	38.90	–	–	28.24	28.89	42.87	–	–
Lithuania	24.39	23.41	52.20	–	–	25.46	19.83	54.71	–	–
Luxembourg	75.89	16.10	8.01	–	–	61.38[s,v]	23.30[r,v]	15.32[r,v]	–	–
Malta	63.36	4.73	31.91	–	–	54.26	10.18[v]	35.56[v]	–	–
Netherlands	47.08	12.75[c]	40.17	–[g]	–	57.54[s,v]	10.68[c,v]	31.78[v]	–[g]	–
Poland	28.50	34.31	37.07	0.13	–	43.62	26.83	29.26	0.29	–
Portugal	47.30	7.31	36.58	8.81	–	47.57[v]	5.79[v]	37.84[v]	8.80[v]	–
Romania	40.18	34.91	24.74	0.17	–	30.66[s]	49.23[s]	19.72[s]	0.40[s]	–
Slovakia	41.05	33.89[p]	25.01	0.05	–	46.26	20.48[p]	33.10	0.15	–
Slovenia	64.61	20.76	14.56	0.07	–	76.53[s]	13.01[s]	10.42[s]	0.04[s]	–
Spain	51.90	20.07	27.83	0.20	–	53.08	18.72	28.03	0.17	–
Sweden	70.64	4.42	24.87	0.07[q]	–	68.95	3.68[q]	27.14	0.22[s]	–
United Kingdom	60.41	9.16	27.95	2.48[r]	–	64.51[r,v]	7.31[r,v]	26.30[r,v]	1.88[r,v]	–
South–East Europe										
Albania	0.00[-1]	52.10[-1,q]	47.90[-1,q]	0.00[-1]	–[-1]	–	–	–	–	–
Bosnia and Herzegovina	–[-2]	12.60[-2,q]	68.75[-2,q]	1.06[-2,q]	17.59[-2,q]	58.42[s]	5.81[s]	35.64[s]	0.12[s]	–
Macedonia, FYR	21.14	46.41	32.45	–	–	11.50[-3]	43.78[-3]	44.72[-3]	–[-3]	–[-3]
Montenegro	5.15[-2]	14.87[-2]	79.98[-2]	0.00[-2]	–[-2]	49.31[s]	16.00[s]	32.02[s]	2.68[s]	–[s]
Serbia	14.32	30.87	54.78	0.03	–	13.27	33.36	53.34	0.03	–

R&D expenditure by source of funds (%)												
2009						2013						
Business enterprise	Government	Higher education	Private non–profit	Abroad	Not elsewhere classified	Business enterprise	Government	Higher education	Private non–profit	Abroad	Not elsewhere classified	
												North America
48.52	34.56^{r}	6.73^{r}	3.13	7.07	–	46.45^{v}	34.86^{r,v}	8.85^{r,v}	3.88^{v}	5.95^{v}	–	Canada
60.90^{o}	32.65^{o}	2.94^{o}	3.51^{o}	–^{g}	–	59.13$^{-1,o,s,v}$	30.79$^{-1,o,v}$	2.98$^{-1,o,v}$	3.30$^{-1,o,v}$	3.80$^{-1,g}$	–$^{-1}$	United States of America
												Latin America
21.44	73.18	3.84	0.87	0.67	0.00	21.34^{-1}	74.01^{-1}	3.11^{-1}	0.96^{-1}	0.58^{-1}	–$^{-1}$	Argentina
–	–	–	–	–	–	–	–	–	–	–	–	Belize
5.20	51.19	26.55	2.05	1.86	13.15	–	–	–	–	–	–	Bolivia
45.54	52.29	2.16	–	–	–	43.07^{-1}	54.93^{-1}	2.00^{-1}	–$^{-1}$	–$^{-1}$	–$^{-1}$	Brazil
26.96	38.32	13.96	1.70	19.05	–	34.95^{-1}	35.96^{-1}	9.42^{-1}	2.13^{-1}	17.54^{-1}	–$^{-1}$	Chile
18.68	56.12	16.70	5.10	3.40	–	29.02	45.77	14.83	8.00	2.38	–	Colombia
28.73	53.04	–	2.82	1.66	13.74	18.85^{-2}	61.98^{-2}	–$^{-2}$	0.74^{-2}	6.54^{-2}	11.89^{-2}	Costa Rica
0.19^{h}	41.21^{h}	7.45^{h}	0.51^{h}	9.80^{h}	40.84^{h}	0.42$^{-2,h}$	28.45$^{-2,h}$	8.09$^{-2,h}$	0.47$^{-2,h}$	4.46$^{-2,h}$	58.12$^{-2,h}$	Ecuador
23.13	64.58	0.63	0.12	11.25	0.30	2.75^{-1}	11.73^{-1}	74.33^{-1}	2.63^{-1}	9.15^{-1}	–$^{-1}$	El Salvador
–	22.78^{q}	29.48^{q}	–	47.74^{q}	–	–$^{-1}$	23.51$^{-1,q}$	27.48$^{-1,q}$	–$^{-1}$	49.01$^{-1,q}$	–$^{-1}$	Guatemala
–	–	–	–	–	–	–	–	–	–	–	–	Guyana
–	–	–	–	–	–	–	–	–	–	–	–	Honduras
39.06	53.17	5.75	0.27	1.75	–	31.65	65.50	1.52	0.67	0.66	–	Mexico
–	–	–	–	–	–	–	–	–	–	–	–	Nicaragua
3.61	50.00	4.99	16.43	24.95	0.01	18.86^{-2}	46.73^{-2}	5.00^{-2}	8.66^{-2}	20.73^{-2}	0.02^{-2}	Panama
0.25^{-1}	76.20^{-1}	9.20^{-1}	2.10^{-1}	12.25^{-1}	–$^{-1}$	0.85^{-1}	82.55^{-1}	3.71^{-1}	2.86^{-1}	7.71^{-1}	2.32^{-1}	Paraguay
–	–	–	–	–	–	–	–	–	–	–	–	Peru
–	–	–	–	–	–	–	–	–	–	–	–	Suriname
38.86	32.99	24.62	0.59	1.83	1.11	15.03^{-1}	32.97^{-1}	43.43^{-1}	0.92^{-1}	7.65^{-1}	–$^{-1}$	Uruguay
–	–	–	–	–	–	–	–	–	–	–	–	Venezuela
												Caribbean
–	–	–	–	–	–	–	–	–	–	–	–	Antigua and Barbuda
–	–	–	–	–	–	–	–	–	–	–	–	Bahamas
–	–	–	–	–	–	–	–	–	–	–	–	Barbados
15.01	75.01	–	–	9.98	–	19.99	69.99	–	–	10.02	–	Cuba
–	–	–	–	–	–	–	–	–	–	–	–	Dominica
–	–	–	–	–	–	–	–	–	–	–	–	Dominican Rep.
–	–	–	–	–	–	–	–	–	–	–	–	Grenada
–	–	–	–	–	–	–	–	–	–	–	–	Haiti
–	–	–	–	–	–	–	–	–	–	–	–	Jamaica
–	–	–	–	–	–	–	–	–	–	–	–	St Kitts and Nevis
–	–	–	–	–	–	–	–	–	–	–	–	St Lucia
–	–	–	–	–	–	–	–	–	–	–	–	St Vincent and the Grenadines
–	–	–	–	–	–	–	–	–	–	–	–	Trinidad and Tobago
												European Union
47.06	34.91	0.67	0.56	16.79	–	44.12^{r,v}	39.07^{c,r,v}	–^{g}	0.46^{r,v}	16.36^{r,v}	–	Austria
58.62	25.31	3.21	0.75	12.11	–	60.15^{-2}	23.42^{-2}	2.87^{-2}	0.60^{-2}	12.96^{-2}	–$^{-2}$	Belgium
30.23	60.47	0.74	0.18	8.38	–	19.51	31.62	0.13	0.46	48.27	–	Bulgaria
39.79	51.19	1.95	0.12	6.96	–	42.79	39.74	1.68	0.31	15.50	–	Croatia
15.73	69.00	2.76	0.45	12.06	–	10.86^{-1}	66.38^{-1}	4.59^{-1}	0.69^{-1}	17.48^{-1}	–$^{-1}$	Cyprus
39.76	47.77	1.18	0.02	11.28	–	37.60	34.74	0.45	0.06	27.15	–	Czech Rep.
62.14	26.14	–^{g}	3.12	8.61	–	59.78^{r,v}	29.27^{r,v}	–^{g}	3.78^{r,v}	7.18^{r,v}	–	Denmark
38.49	48.82	0.69	0.68	11.33	–	42.05	47.22	0.27	0.11	10.34	–	Estonia
68.10	24.00	0.14	1.15	6.61	–	60.84	26.03^{s}	0.23	1.36	11.54	–	Finland
52.27	38.71	1.20	0.79	7.03	–	55.38$^{-1,s}$	34.97$^{-1,s}$	1.22$^{-1,s}$	0.82$^{-1,s}$	7.62$^{-1,s}$	–$^{-1}$	France
66.13	29.77	–	0.26	3.85	–	66.07^{-1}	29.21^{-1}	–$^{-1}$	0.39^{-1}	4.32^{-1}	–$^{-1}$	Germany
33.48^{r}	54.75^{r}	2.12^{r}	0.94^{r}	8.71^{r}	–	30.28	52.27	2.60	0.86	13.98	–	Greece
46.43	41.98	–	0.69	10.90	–	46.80	35.88	–	0.75	16.57	–	Hungary
52.09^{r}	29.80^{r}	1.11^{r}	0.50^{r}	16.51^{r}	–	50.34$^{-1,r}$	27.26$^{-1,r}$	0.64$^{-1,r}$	0.41$^{-1,r}$	21.36$^{-1,r}$	–$^{-1}$	Ireland
44.16	42.15	1.26	3.01	9.42	–	44.29^{-1}	42.55^{-1}	0.94^{-1}	2.78^{-1}	9.45^{-1}	–$^{-1}$	Italy
36.90	44.74	3.00	–	15.36	–	21.79	23.94	2.65	–	51.61	–	Latvia
30.81	52.68	3.21	0.29	13.01	–	27.47	34.54	0.13	0.75	37.11	–	Lithuania
70.27	24.26	0.04	0.07	5.37	–	47.81^{-2}	30.52^{-2}	0.06^{-2}	1.20^{-2}	20.41^{-2}	–$^{-2}$	Luxembourg
51.57	30.01	0.00	0.05	18.37	–	44.35^{v}	33.86^{v}	1.29^{v}	0.18^{v}	20.33^{v}	–	Malta
45.15	40.89	0.29	2.82	10.85	–	47.10^{s,v}	34.33^{s,v}	0.39^{s,v}	3.91^{s,v}	14.27^{s,v}	–	Netherlands
27.10	60.44	6.70	0.26	5.50	–	37.33	47.24	2.13	0.18	13.12	–	Poland
43.87	45.46	2.85	3.73	4.09	–	46.04^{-1}	43.13^{-1}	3.58^{-1}	2.08^{-1}	5.17^{-1}	–$^{-1}$	Portugal
34.75	54.92	1.91	0.08	8.34	–	31.02^{s}	52.29^{s}	1.15^{s}	0.05^{s}	15.50^{s}	–	Romania
35.11	50.56^{q}	0.59	0.96	12.78	–	40.19	38.90^{q}	2.74	0.20	17.97	–	Slovakia
57.98	35.66	0.29	0.03	6.04	–	63.85^{s}	26.87^{s}	0.35^{s}	0.02^{s}	8.91^{s}	–	Slovenia
43.36	47.10	3.45	0.63	5.46	–	46.30	41.63	4.08	0.63	7.36	–	Spain
59.14	27.26	0.63	2.58	10.39	–	60.95^{q}	28.20^{q}	0.99^{q}	3.05^{q}	6.80^{q}	–	Sweden
44.54^{r}	32.55	1.28^{r}	4.99^{r}	16.64^{r}	–	46.55^{r,v}	26.99^{r,v}	1.09^{r,v}	4.73^{r,v}	20.65^{r,v}	–	United Kingdom
												South–East Europe
3.26$^{-1,q}$	80.80$^{-1,q}$	8.57$^{-1,q}$	0.00^{-1}	7.37$^{-1,q}$	–$^{-1}$	–	–	–	–	–	–	Albania
–	–	–	–	–	–	1.83	25.35	0.00	0.00	53.90	18.92	Bosnia and Herzegovina
7.79$^{-7,r}$	76.31$^{-7,r}$	7.33$^{-7,r}$	0.02$^{-7,r}$	8.55$^{-7,r}$	–$^{-7}$	–	–	–	–	–	–	Macedonia, FYR
–	–	–	–	–	–	42.32	31.66	3.50	0.02	22.52	–	Montenegro
8.33	62.87	20.86	0.76	7.18	–	7.53	59.51	25.12	0.03	7.81	–	Serbia

Table S2: R&D expenditure by sector of performance and source of funds, 2009 and 2013 (%)

	R&D expenditure by sector of performance (%)									
	2009					2013				
	Business enterprise	Government	Higher education	Private non–profit	Not elsewhere classified	Business enterprise	Government	Higher education	Private non–profit	Not elsewhere classified
Other Europe and West Asia										
Armenia	–	89.65[q]	10.35[q]	–	–	–	88.63[q]	11.37[q]	–	–
Azerbaijan	22.00	71.73	6.27	0.00	–	10.33	85.49	4.02	0.16	–
Belarus	56.39	29.96	13.62	0.03	–	65.32	23.82	10.84	0.02	–
Georgia	–[-4]	73.18[-4]	26.82[-4]	–[-4]	–[-4]	–	72.31[s,u]	27.69[s,u]	–	–
Iran, Islamic Rep. of	10.61[-1]	56.07[-1]	33.32[-1]	–[-1]	–[-1]	–	–	–	–	–
Israel	83.53[p]	1.85[p]	13.32[p]	1.30[p]	–	82.74[p]	2.13[p]	14.07[p]	1.05[p]	–
Moldova, Rep. of	11.30	77.08	11.62	–	–	19.86	69.78	10.37	–	–
Russian Federation	62.38	30.26	7.13	0.23	–	60.60	30.26	9.01	0.13	–
Turkey	40.00	12.57	47.43	–	–	47.49	10.42	42.09	–	–
Ukraine	54.77	38.68	6.54	0.00	–	55.26	38.58	6.17	–	–
European Free Trade Assoc.										
Iceland	50.32	22.09	25.13	2.46	–	53.14[-2]	17.74[-2,s]	26.37[-2]	2.75[-2,s]	–[-2]
Liechtenstein	–	–	–	–	–	–	–	–	–	–
Norway	51.57	16.38	32.04	–	–	52.54	15.97	31.50	–	–
Switzerland	73.50[-1]	0.74[-1]	24.17[-1]	1.60[-1]	–[-1]	69.26[-1]	0.76[-1]	28.15[-1]	1.84[-1]	–[-1]
Sub–Saharan Africa										
Angola	–	–	–	–	–	–	–	–	–	–
Benin	–	–	–	–	–	–	–	–	–	–
Botswana	15.57[-4]	79.40[-4]	1.21[-4]	3.83[-4]	–[-4]	10.71[-1,s]	41.63[-1,s]	22.95[-1,s]	24.71[-1,s]	–[-1]
Burkina Faso	–[-2]	72.22[-2]	–[-2]	21.12[-2]	6.67[-2]	–	–	–	–	–
Burundi	–[-1]	92.83[-1,q]	6.96[-1,q]	0.21[-1,q]	–[-1]	–[-3]	87.15[-3,q]	4.81[-3,q]	8.04[-3,q]	–[-3]
Cabo Verde	–	–	–	–	–	–[-2]	–[-2]	100.00[-2]	–[-2]	–[-2]
Cameroon	–	–	–	–	–	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	–	–	–	–	–
Congo	–	–	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of	–	100.00	–	–	–	–	–	–	–	–
Côte d'Ivoire	–	–	–	–	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–	–	–	–	–
Equatorial Guinea	–	–	–	–	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–	–	–	–	–
Ethiopia	–[-2]	84.41[-2]	14.60[-2]	0.99[-2]	–[-2]	1.17	24.49	74.10	0.23	–
Gabon	–	–	–	–	–	–	–	–	–	–
Gambia	–	–	–	–	–	–[-2]	54.44[-2,b]	–[-2]	45.56[-2,b]	–[-2]
Ghana	4.94[-2]	92.76[-2]	2.30[-2]	–[-2]	–[-2]	0.15[-3,s]	96.05[-3,s]	3.80[-3]	0.01[-3]	–[-3]
Guinea	–	–	–	–	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–	–	–
Kenya	11.68[-2]	35.36[-2]	29.84[-2]	23.12[-2]	–[-2]	8.66[-3,s]	40.64[-3,s]	39.05[-3,s]	11.65[-3,s]	–[-3]
Lesotho	–	7.67[q]	92.33[q]	–	–	–[-2]	–[-2]	100.00[-2,q]	–[-2]	–[-2]
Liberia	–	–	–	–	–	–	–	–	–	–
Madagascar	–	34.50	65.50	–	–	–[-2]	56.39[-2,s]	43.61[-2,s]	–[-2]	–[-2]
Malawi	–	–	–	–	–	–	–	–	–	–
Mali	2.97[-2,q]	–[-2]	97.03[-2,q]	–[-2]	–[-2]	–[-3]	82.58[-3]	17.42[-3]	–[-3]	–[-3]
Mauritius	–	–	–	–	–	–[-1]	73.36[-1]	24.76[-1]	1.86[-1]	–[-1]
Mozambique	–[-1]	95.45[-1]	–[-1]	4.55[-1]	–[-1]	–[-3]	54.88[-3]	35.99[-3]	9.13[-3]	–[-3]
Namibia	–	–	–	–	–	12.82[-3]	–[-3]	87.18[-3]	–[-3]	–[-3]
Niger	–	–	–	–	–	–	–	–	–	–
Nigeria	–[-2]	35.19[-2]	64.81[-2]	–[-2]	–[-2]	–	–	–	–	–
Rwanda	–	–	–	–	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–	–	–	–	–
Senegal	0.86[-1]	33.48[-1]	40.66[-1]	25.00[-1]	–[-1]	0.34[-3]	52.05[-3]	31.43[-3]	16.18[-3]	–[-3]
Seychelles	–[-4]	97.05[-4]	–[-4]	2.95[-4]	–[-4]	–	–	–	–	–
Sierra Leone	–	–	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–	–	–
South Africa	53.16	21.60	24.34	0.90	–	44.28[-1]	22.89[-1]	30.72[-1]	2.11[-1]	–[-1]
South Sudan	–	–	–	–	–	–	–	–	–	–
Swaziland	–	–	–	–	–	–	–	–	–	–
Tanzania	–[-2]	42.10[-2]	54.12[-2]	3.79[-2]	–[-2]	–[-3]	13.75[-3]	86.25[-3]	–[-3]	–[-3]
Togo	–	–	–	–	–	–[-1]	39.83[-1]	60.17[-1]	–[-1]	–[-1]
Uganda	8.23	64.35	17.56	9.85	–	34.77[-3,s]	38.58[-3]	25.41[-3]	1.25[-3]	–[-3]
Zambia	2.02[-1]	19.32[-1]	78.17[-1]	0.48[-1]	–[-1]	–	–	–	–	–
Zimbabwe	–	–	–	–	–	–	–	–	–	–
Arab states										
Algeria	–	–	–	–	–	–	–	–	–	–
Bahrain	–	–	–	–	–	–	–	100.00[q]	–	–
Egypt	–	45.41	54.72	–	–	–	44.54	55.46	–	–
Iraq	–	93.84	6.16	–	–	–[-2]	91.96[-2]	8.04[-2]	–[-2]	–[-2]
Jordan	–	–	–	–	–	–	–	–	–	–
Kuwait	–	100.00	–	–	–	–	38.91	60.85	–	0.25
Lebanon	–	–	–	–	–	–	–	–	–	–

	R&D expenditure by source of funds (%)											
	2009						2013					
	Business enterprise	Government	Higher education	Private non-profit	Abroad	Not elsewhere classified	Business enterprise	Government	Higher education	Private non-profit	Abroad	Not elsewhere classified
Other Europe and West Asia												
Armenia	–	55.57^{q}	0.00	–	3.91^{q}	40.51^{q}	–	66.31^{q}	–	–	2.79^{q}	30.90^{q}
Azerbaijan	24.76	74.35	0.00^{g}	0.82	0.07	–	30.49^{s}	68.20^{s}	0.82^{s}	0.33	0.16	–
Belarus	28.82	62.56	0.00	0.13	8.49	–	43.79	48.26	–	–	7.95	–
Georgia	–	–	–	–	–	–	–	–	–	–	–	–
Iran, Islamic Rep. of	30.92^{-1}	61.64^{-1}	7.45^{-1}	–$^{-1}$	–$^{-1}$	–$^{-1}$	–	–	–	–	–	–
Israel	37.53^{p}	12.84^{p}	1.29^{p}	1.65^{p}	46.70^{p}	–	35.60$^{-1,p}$	12.13$^{-1,p}$	1.75$^{-1,p}$	1.74$^{-1,p}$	48.77$^{-1,p}$	–$^{-1}$
Moldova, Rep. of	–^{g}	–^{g}	–^{g}	–^{g}	6.49	93.51	–^{g}	–^{g}	–^{g}	–^{g}	11.80	88.20
Russian Federation	26.59	66.46	0.39	0.10	6.46	–	28.16	67.64	1.04	0.12	3.03	–
Turkey	40.97	33.96	20.29	3.66	1.13	–	48.87	26.55	20.44	3.30	0.83	–
Ukraine	25.90	49.77	0.31	0.08	22.29	1.65	28.99	47.73	0.18	0.14	21.61	1.34
European Free Trade Assoc.												
Iceland	47.81	40.24	0.00	0.58	11.38	–	49.85$^{-2,s}$	39.99$^{-2,s}$	1.36$^{-2,s}$	0.58$^{-2,s}$	8.22$^{-2,s}$	–$^{-2}$
Liechtenstein	–	–	–	–	–	–	–	–	–	–	–	–
Norway	43.61	46.77	0.43	0.99	8.20	–	43.15	45.79	0.53	1.02	9.51	–
Switzerland	68.19^{-1}	22.84^{-1}	2.33^{-1}	0.69^{-1}	5.95^{-1}	–$^{-1}$	60.78^{-1}	25.42^{-1}	1.16^{-1}	0.57^{-1}	12.07^{-1}	–$^{-1}$
Sub–Saharan Africa												
Angola	–	–	–	–	–	–	–	–	–	–	–	–
Benin	–	–	–	–	–	–	–	–	–	–	–	–
Botswana	–	–	–	–	–	–	5.81^{-1}	73.88^{-1}	12.56^{-1}	0.74^{-1}	6.81^{-1}	0.20^{-1}
Burkina Faso	11.93	9.05	12.22	1.27	59.61	5.92	–	–	–	–	–	–
Burundi	–$^{-1}$	59.87$^{-1,q}$	0.21$^{-1,q}$	–$^{-1}$	39.92$^{-1,q}$	–$^{-1}$	–	–	–	–	–	–
Cabo Verde	–	–	–	–	–	–	–$^{-2}$	100.00$^{-2,l,q}$	–$^{-2}$	–$^{-2}$	–$^{-2}$	–$^{-2}$
Cameroon	–	–	–	–	–	–	–	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	–	–	–	–	–	–	–
Congo	–	–	–	–	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of	–	100.00	–	–	–	–	–	–	–	–	–	–
Côte d'Ivoire	–	–	–	–	–	–	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–	–	–	–	–	–	–
Equatorial Guinea	–	–	–	–	–	–	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–	–	–	–	–	–	–
Ethiopia	–$^{-2}$	71.74^{-2}	0.00$^{-2,g}$	0.73^{-2}	27.00^{-2}	0.53^{-2}	0.75	79.07	1.80	0.23	2.15	16.01
Gabon	29.26	58.09	9.55	–	3.09	0.01	–	–	–	–	–	–
Gambia	–	–	–	–	–	–	–$^{-2}$	38.54$^{-2,b}$	–$^{-2}$	45.56$^{-2,b}$	15.90$^{-2,b}$	–$^{-2}$
Ghana	50.86^{-2}	36.55^{-2}	0.65^{-2}	–$^{-2}$	11.95^{-2}	–$^{-2}$	0.10$^{-3,s}$	68.30$^{-3,s}$	0.27^{-3}	0.11^{-3}	31.22^{-3}	–$^{-3}$
Guinea	–	–	–	–	–	–	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–	–	–	–	–
Kenya	16.83^{-2}	26.15^{-2}	26.16^{-2}	13.24^{-2}	17.62^{-2}	–$^{-2}$	4.34$^{-3,s}$	25.96$^{-3,s}$	19.03$^{-3,s}$	3.53$^{-3,s}$	47.14$^{-3,s}$	–$^{-3}$
Lesotho	3.38^{q}	14.96^{q}	2.80^{q}	–	–	78.86^{q}	–$^{-2}$	–$^{-2}$	44.66$^{-2,c,q}$	–$^{-2}$	3.45$^{-2,q}$	51.89$^{-2,q}$
Liberia	–	–	–	–	–	–	–	–	–	–	–	–
Madagascar	–	89.42^{e}	–^{n}	–	10.58	–	–$^{-2}$	100.00$^{-2,e,s}$	–$^{-2,n}$	–$^{-2}$	–$^{-2}$	–$^{-2}$
Malawi	–	–	–	–	–	–	–	–	–	–	–	–
Mali	10.10$^{-2,q}$	40.86$^{-2,q}$	–$^{-2}$	–$^{-2}$	49.04$^{-2,q}$	–$^{-2}$	–$^{-3}$	91.19$^{-3,s}$	–$^{-3}$	–$^{-3}$	8.81^{-3}	–$^{-3}$
Mauritius	–$^{-4}$	100.00$^{-4,b,u}$	–$^{-4}$	–$^{-4}$	–$^{-4}$	–$^{-4}$	0.27$^{-1,h}$	72.43$^{-1,h}$	20.73$^{-1,h}$	0.11$^{-1,h}$	6.43$^{-1,h}$	–$^{-1}$
Mozambique	–$^{-1}$	31.13^{-1}	–$^{-1}$	4.55^{-1}	64.32^{-1}	–$^{-1}$	–$^{-3}$	18.84$^{-3,e}$	–$^{-3,n}$	3.02^{-3}	78.14^{-3}	–$^{-3}$
Namibia	–	–	–	–	–	–	19.83^{-3}	78.64^{-3}	–$^{-3}$	–$^{-3}$	1.53^{-3}	–$^{-3}$
Niger	–	–	–	–	–	–	–	–	–	–	–	–
Nigeria	0.16^{-2}	96.36^{-2}	0.08^{-2}	1.73^{-2}	1.04^{-2}	0.64^{-2}	–	–	–	–	–	–
Rwanda	–	–	–	–	–	–	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–	–	–	–	–	–	–
Senegal	4.04^{-1}	57.06^{-1}	0.30^{-1}	0.27^{-1}	38.27^{-1}	0.05^{-1}	4.10^{-3}	47.62^{-3}	0.03^{-3}	3.23^{-3}	40.53^{-3}	4.49^{-3}
Seychelles	–	–	–	–	–	–	–	–	–	–	–	–
Sierra Leone	–	–	–	–	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–	–	–	–	–
South Africa	42.51	44.44	0.05	0.88	12.11	–	38.34^{-1}	45.38^{-1}	0.77^{-1}	2.46^{-1}	13.06^{-1}	–$^{-1}$
South Sudan	–	–	–	–	–	–	–	–	–	–	–	–
Swaziland	–	–	–	–	–	–	–	–	–	–	–	–
Tanzania	–$^{-2}$	60.58^{-2}	0.00^{-2}	1.06^{-2}	38.36^{-2}	–$^{-2}$	0.08^{-3}	57.53^{-3}	0.33^{-3}	0.05^{-3}	42.00^{-3}	–$^{-3}$
Togo	–	–	–	–	–	–	–$^{-1}$	84.87^{-1}	–$^{-1}$	3.08^{-1}	12.06^{-1}	–$^{-1}$
Uganda	8.23	48.07	17.56	0.08	26.06	–	13.67^{-3}	21.94^{-3}	1.04^{-3}	6.05^{-3}	57.30^{-3}	–$^{-3}$
Zambia	3.23^{-1}	94.83^{-1}	–$^{-1}$	0.32^{-1}	1.62^{-1}	–$^{-1}$	–	–	–	–	–	–
Zimbabwe	–	–	–	–	–	–	–	–	–	–	–	–
Arab states												
Algeria	–	–	–	–	–	–	–	–	–	–	–	–
Bahrain	–	–	–	–	–	–	0.00^{l,q}	68.40^{l,q}	0.00^{l,q}	1.16^{l,q}	30.44^{l,q}	–^{l,q}
Egypt	–	–	–	–	–	–	–	–	–	–	–	–
Iraq	–	100.00^{e}	–^{n}	–	–	–	0.00^{-2}	100.00$^{-2,e}$	–$^{-2,n}$	0.00^{-2}	0.00^{-2}	–$^{-2}$
Jordan	–	–	–	–	–	–	–	–	–	–	–	–
Kuwait	2.33^{k}	96.49^{k}	–	–	1.18^{k}	–	1.41^{h}	92.95^{h}	0.17^{h}	5.47^{h}	0.00^{h}	–^{h}
Lebanon	–	–	–	–	–	–	–	–	–	–	–	–

Table S2: R&D expenditure by sector of performance and source of funds, 2009 and 2013 (%)

	R&D expenditure by sector of performance (%)									
	2009					2013				
	Business enterprise	Government	Higher education	Private non–profit	Not elsewhere classified	Business enterprise	Government	Higher education	Private non–profit	Not elsewhere classified
Libya	–	–	–	–	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–	–	–	–	–
Morocco	22.05[-3]	25.60[-3]	52.35[-3]	–[-3]	–[-3]	29.94[-3]	23.07[-3]	47.00[-3]	–[-3]	–[-3]
Oman	–	–	–	–	–	24.08	41.58	34.33	0.01	–
Palestine	–	–	–	–	–	–	–	–	–	–
Qatar	–	–	–	–	–	25.84[-1]	32.28[-1]	41.88[-1]	–[-1]	–[-1]
Saudi Arabia	–	–	–	–	–	–	–	–	–	–
Sudan	33.71[-4,r]	39.20[-4,r]	27.09[-4,r]	–[-4]	–[-4]	–	–	–	–	–
Syrian Arab Rep.	–	–	–	–	–	–	–	–	–	–
Tunisia	–	–	–	–	–	–	–	–	–	–
United Arab Emirates	–	–	–	–	–	28.62[-2,r]	39.65[-2,r]	29.33[-2,r]	2.40[-2,r]	–[-2,r]
Yemen	–	–	–	–	–	–	–	–	–	–
Central Asia										
Kazakhstan	32.75	38.51	15.19	13.55	–	29.43	29.68	30.69	10.20	–
Kyrgyzstan	23.36	65.18	11.46	0.00	–	23.33[-2]	62.04[-2]	14.63[-2]	0.00[-2]	–[-2]
Mongolia	5.52[q]	64.37	9.69[q]	0.00[q]	20.41[q]	5.45[q]	84.30[q]	10.25[q]	–	–
Tajikistan	–	86.22	13.78	–	–	–	88.26	11.74	–	–
Turkmenistan	–	–	–	–	–	–	–	–	–	–
Uzbekistan	–	–	–	–	–	–	–	–	–	–
South Asia										
Afghanistan	–	–	–	–	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–	–	–	–	–
India	34.16[f]	61.69	4.15	0.00[m]	–	35.46[-2,f]	60.48[-2]	4.06[-2]	0.00[-2,m]	–[-2]
Maldives	–	–	–	–	–	–	–	–	–	–
Nepal	–	100.00[u]	–	–	–	–[-3]	100.00[-3,u]	–[-3]	–[-3]	–[-3]
Pakistan	–	74.99	25.01	–	–	–	67.06	32.94	–	–
Sri Lanka	18.32[-1,f]	56.91[-1]	24.78[-1]	0.00[-1,m]	–[-1]	43.75[-3,s]	44.75[-3]	11.49[-3]	0.02[-3,q,s]	–[-3]
South–East Asia										
Brunei Darussalam	–[-5]	91.59[-5]	8.41[-5]	0.00[-5]	–[-5]	–	–	–	–	–
Cambodia	12.08[-7,q,r]	25.33[-7,q,r]	11.80[-7,q,r]	50.79[-7,q,r]	–[-7,r]	–	–	–	–	–
China	73.23	18.71	8.07	–	–	76.61	16.16	7.23	–	–
China, Hong Kong SAR	42.65[f]	4.08	53.26	0.00[m]	–	44.87[-1,f]	4.00[-1]	51.14[-1]	–[-1,m]	–[-1]
China, Macao SAR	0.00[-1]	0.00[-1]	98.63[-1]	1.37[-1]	–[-1]	0.37	–	96.24	2.87	0.51
Indonesia	18.85[r]	43.22[r]	37.93[r]	–	–	25.68[r]	39.39[r]	34.93[r]	–	–[r]
Japan	75.76	9.21	13.41	1.61	–	76.09	9.17	13.47	1.28	–
Korea, DPR	–	–	–	–	–	–	–	–	–	–
Korea, Rep. of	74.26	13.02	11.08	1.64	–	78.51	10.91	9.24	1.33	–
Lao PDR	36.89[-7,q]	50.91[-7,q]	12.20[-7,q]	0.00[-7]	–[-7]	–	–	–	–	–
Malaysia	69.86	6.38	23.77	0.00	–	64.45[-1]	6.88[-1]	28.67[-1]	0.01[-1]	–[-1]
Myanmar	–	–	–	–	–	–	–	–	–	–
Philippines	56.95[-2]	17.65[-2]	23.25[-2]	2.15[-2]	–[-2]	–	–	–	–	–
Singapore	61.63	11.30	27.06	–	–	60.94[-1]	10.01[-1]	29.05[-1]	–[-1]	–[-1]
Thailand	41.21	32.75	24.94	1.11	–	50.61[-2]	18.87[-2]	30.14[-2]	0.38[-2]	–[-2]
Timor–Leste	–	–	–	–	–	–	–	–	–	–
Viet Nam	14.55[-7]	66.43[-7]	17.91[-7]	1.12[-7]	–[-7]	26.01[-2]	58.32[-2]	14.37[-2]	1.29[-2]	–[-2]
Oceania										
Australia	61.10[-1]	12.09[-1]	24.18[-1]	2.63[-1]	–[-1]	57.86[-2]	11.21[-2,r]	28.06[-2,r]	2.98[-2,r]	–[-2]
New Zealand	41.76	25.28	32.96	–	–	45.45[-2]	22.70[-2]	31.85[-2]	–[-2]	–[-2]
Cook Islands	–	–	–	–	–	–	–	–	–	–
Fiji	–	–	–	–	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–	–	–	–	–
Nauru	–	–	–	–	–	–	–	–	–	–
Niue	–	–	–	–	–	–	–	–	–	–
Palau	–	–	–	–	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–	–	–	–	–
Samoa	–	–	–	–	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–	–	–	–	–
Tonga	–	–	–	–	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–	–	–	–	–

Source: UNESCO Institute for Statistics (UIS), August, 2015

N.B.: See Key To All Tables at the end of Table S10.

R&D expenditure by source of funds (%)												
2009						2013						
Business enterprise	Government	Higher education	Private non–profit	Abroad	Not elsewhere classified	Business enterprise	Government	Higher education	Private non–profit	Abroad	Not elsewhere classified	
–	–	–	–	–	–	–	–	–	–	–	–	Libya
–	–	–	–	–	–	–	–	–	–	–	–	Mauritania
22.70^{-3}	26.12^{-3}	48.56^{-3}	–$^{-3}$	2.61^{-3}	–$^{-3}$	29.94^{-3}	23.07^{-3}	45.28^{-3}	–$^{-3}$	1.71^{-3}	–$^{-3}$	Morocco
–	–	–	–	–	–	24.55	48.60	24.44	0.07	0.00	2.34^{r}	Oman
–	–	–	–	–	–	–	–	–	–	–	–	Palestine
–	–	–	–	–	–	24.18^{-1}	31.18^{-1}	36.56^{-1}	5.60^{-1}	2.42^{-1}	0.05^{-1}	Qatar
–	–	–	–	–	–	–	–	–	–	–	–	Saudi Arabia
–	–	–	–	–	–	–	–	–	–	–	–	Sudan
–	–	–	–	–	–	–	–	–	–	–	–	Syrian Arab Rep.
16.00	79.00^{e}	–^{n}	0.00	5.10	–	18.70^{-1}	76.90$^{-1,e}$	–$^{-1,n}$	0.00^{-1}	4.40^{-1}	–$^{-1}$	Tunisia
–	–	–	–	–	–	–	–	–	–	–	–	United Arab Emirates
–	–	–	–	–	–	–	–	–	–	–	–	Yemen
												Central Asia
50.74^{-1}	31.37^{-1}	14.74^{-1}	2.20^{-1}	0.96^{-1}	–$^{-1}$	28.92	63.68	–	–	0.76	6.64	Kazakhstan
36.38^{-4}	63.62^{-4}	0.00^{-4}	0.00^{-4}	0.01^{-4}	–$^{-4}$	38.58$^{-2,s}$	57.66$^{-2,s}$	1.43$^{-2,s}$	0.00^{-2}	0.87$^{-2,s}$	1.45$^{-2,s}$	Kyrgyzstan
2.90^{q}	61.52^{q}	1.96^{q}	0.00	1.44^{q}	32.17^{q}	8.31^{q}	73.95^{q}	1.83^{q}	–	4.90^{q}	11.02^{q}	Mongolia
1.08^{t}	82.07^{t}	0.64^{t}	–	–	16.14^{t}	–	92.45	0.21	–	0.21	7.13	Tajikistan
–	–	–	–	–	–	–	–	–	–	–	–	Turkmenistan
–	–	–	–	–	–	–	–	–	–	–	–	Uzbekistan
												South Asia
–	–	–	–	–	–	–	–	–	–	–	–	Afghanistan
–	–	–	–	–	–	–	–	–	–	–	–	Bangladesh
–	–	–	–	–	–	–	–	–	–	–	–	Bhutan
–	–	–	–	–	–	–	–	–	–	–	–	India
–	–	–	–	–	–	–	–	–	–	–	–	Maldives
–	–	–	–	–	–	–	–	–	–	–	–	Nepal
–	84.03	12.11	1.66	0.92	1.28	–	75.26^{h}	20.00^{h}	1.71^{h}	1.31^{h}	1.71^{h}	Pakistan
19.89$^{-1,f}$	71.80$^{-1,e}$	0.00$^{-1,n}$	0.00$^{-1,m}$	4.27^{-1}	4.04^{-1}	40.93$^{-3,s}$	55.90^{-3}	0.19^{-3}	0.00^{-3}	2.72^{-3}	0.26^{-3}	Sri Lanka
												South–East Asia
1.58^{-5}	91.01^{-5}	7.41^{-5}	0.00^{-5}	0.00^{-5}	–$^{-5}$	–	–	–	–	–	–	Brunei Darussalam
–$^{-7}$	17.93$^{-7,q,r}$	–$^{-7}$	43.00$^{-7,q,r}$	28.44$^{-7,q,r}$	10.62$^{-7,q,r}$	–	–	–	–	–	–	Cambodia
71.74^{t}	23.41^{t}	–	–	1.35^{t}	–	74.60^{t}	21.11^{t}	–	–	0.89^{t}	–	China
45.83^{f}	47.96	0.12	0.00^{m}	6.09	–	49.73$^{-1,f}$	45.60^{-1}	0.02^{-1}	–$^{-1,m}$	4.65^{-1}	–$^{-1}$	China, Hong Kong SAR
0.18^{-1}	91.74^{-1}	6.42^{-1}	1.37^{-1}	0.00^{-1}	0.28^{-1}	–	90.55	8.13	1.32	0.00	–	China, Macao SAR
14.69$^{-8,f,q}$	84.51^{-8}	0.15^{-8}	0.00$^{-8,m}$	–$^{-8}$	0.65^{-8}	–	–	–	–	–	–	Indonesia
75.27	17.67^{r}	5.91^{r}	0.74	0.42	–	75.48	17.30^{r}	5.86^{r}	0.83	0.52	–	Japan
–	–	–	–	–	–	–	–	–	–	–	–	Korea, DPR
71.08	27.40	0.90	0.41	0.21	–	75.68	22.83	0.73	0.46	0.30	–	Korea, Rep. of
36.01$^{-7,q}$	8.00$^{-7,q}$	2.00$^{-7,q}$	0.00$^{-7,g}$	53.99$^{-7,q}$	–$^{-7}$	–	–	–	–	–	–	Lao PDR
68.52	27.12	4.08	0.00	0.23	0.05	60.20^{-1}	29.68^{-1}	2.50^{-1}	0.00^{-1}	4.59^{-1}	3.03^{-1}	Malaysia
–	–	–	–	–	–	–	–	–	–	–	–	Myanmar
61.96^{-2}	26.08^{-2}	6.38^{-2}	0.91^{-2}	4.12^{-2}	0.55^{-2}	–	–	–	–	–	–	Philippines
52.14	40.38	1.54	–	5.95	–	53.37^{-1}	38.54^{-1}	2.18^{-1}	–$^{-1}$	5.91^{-1}	–$^{-1}$	Singapore
41.43	37.89	17.80	0.32	1.00	1.57	51.74^{-2}	30.48^{-2}	13.48^{-2}	0.46^{-2}	2.50^{-2}	1.34^{-2}	Thailand
–	–	–	–	–	–	–	–	–	–	–	–	Timor–Leste
18.06^{-7}	74.11^{-7}	0.66$^{-7,f}$	0.00$^{-7,g}$	6.33^{-7}	0.84^{-7}	28.40^{-2}	64.47^{-2}	3.13^{-2}	0.00^{-2}	3.99^{-2}	–$^{-2}$	Viet Nam
												Oceania
61.91^{-1}	34.60^{-1}	0.12^{-1}	1.77^{-1}	1.61^{-1}	–$^{-1}$	–	–	–	–	–	–	Australia
39.01	44.72	8.30	2.84	5.22	–	39.96^{-2}	41.41^{-2}	9.45^{-2}	2.78^{-2}	6.32^{-2}	–$^{-2}$	New Zealand
–	–	–	–	–	–	–	–	–	–	–	–	Cook Islands
–	–	–	–	–	–	–	–	–	–	–	–	Fiji
–	–	–	–	–	–	–	–	–	–	–	–	Kiribati
–	–	–	–	–	–	–	–	–	–	–	–	Marshall Islands
–	–	–	–	–	–	–	–	–	–	–	–	Micronesia
–	–	–	–	–	–	–	–	–	–	–	–	Nauru
–	–	–	–	–	–	–	–	–	–	–	–	Niue
–	–	–	–	–	–	–	–	–	–	–	–	Palau
–	–	–	–	–	–	–	–	–	–	–	–	Papua New Guinea
–	–	–	–	–	–	–	–	–	–	–	–	Samoa
–	–	–	–	–	–	–	–	–	–	–	–	Solomon Islands
–	–	–	–	–	–	–	–	–	–	–	–	Tonga
–	–	–	–	–	–	–	–	–	–	–	–	Tuvalu
–	–	–	–	–	–	–	–	–	–	–	–	Vanuatu

Table S3: R&D expenditure as a share of GDP and in purchasing power parity (PPP) dollars, 2009-2013

	R&D expenditure as percentage of GDP					R&D expenditure in current PPP$ (000s)		R&D expenditure per capita (current PPP$)	
	2009	2010	2011	2012	2013	2009	2013	2009	2013
North America									
Canada	1.92	1.84	1.79	1.72	1.63[v]	25 027 663	24 565 364[v]	741.5	698.2[v]
United States of America	2.82[o]	2.74[o]	2.77[o]	2.81[o,v]	–	406 000 000[o]	453 544 000[-1,o,v]	1 311.8[o]	1 428.5[-1,o,v]
Latin America									
Argentina	0.48	0.49	0.52	0.58	–	3 418 556	5 159 124[-1]	85.4	125.6[-1]
Belize	–	–	–	–	–	–	–	–	–
Bolivia	0.16	–	–	–	–	78 248	–	7.8	–
Brazil	1.15	1.20	1.20	1.24	–	28 401 334	35 780 779[-1]	146.8	180.1[-1]
Chile	0.35	0.33	0.35	0.36	–	963 991	1 343 656[-1]	56.7	76.9[-1]
Colombia	0.21	0.21	0.22	0.22	0.23	973 270	1 365 135	21.2	28.3
Costa Rica	0.54	0.48	0.47	–	–	287 185	285 072[-2]	62.4	60.2[-2]
Ecuador	0.39	0.40	0.34	–	–	515 346	512 117[-2]	34.9	33.6[-2]
El Salvador	0.08	0.07	0.03	0.03	–	33 277	14 554[-1]	5.4	2.3[-1]
Guatemala	0.06[q]	0.04[q]	0.05[q]	0.04[q]	–	51 110[q]	47 958[-1,q]	3.7[q]	3.2[-1,q]
Guyana	–	–	–	–	–	–	–	–	–
Honduras	0.04[-5]	–	–	–	–	9 214[-5]	–	1.4[-5]	–
Mexico	0.43	0.45	0.42	0.43	0.50	7 008 035	9 984 730	60.2	81.6
Nicaragua	0.03[-7]	–	–	–	–	5 307[-7]	–	1.0[-7]	–
Panama	0.14	0.15	0.18	–	–	69 339	109 671[-2]	19.2	29.3[-2]
Paraguay	0.05[-1]	–	0.06	0.09	–	21 903[-1]	41 865[-1]	3.5[-1]	6.3[-1]
Peru	0.16[-5]	–	–	–	–	263 109[-5]	–	9.6[-5]	–
Suriname	–	–	–	–	–	–	–	–	–
Uruguay	0.44	0.41	0.42	0.24	–	218 160	151 748[-1]	64.9	44.7[-1]
Venezuela	–	–	–	–	–	–	–	–	–
Caribbean									
Antigua and Barbuda	–	–	–	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–	–	–	–
Barbados	–	–	–	–	–	–	–	–	–
Cuba	0.61	0.61	0.27[s]	0.41[s]	0.47	1 199 443	582 720[-2,s]	106.3	51.7[-2,s]
Dominica	–	–	–	–	–	–	–	–	–
Dominican Rep.	–	–	–	–	–	–	–	–	–
Grenada	–	–	–	–	–	–	–	–	–
Haiti	–	–	–	–	–	–	–	–	–
Jamaica	0.06[-7]	–	–	–	–	8 586[-8]	–	3.3[-8]	–
St Kitts and Nevis	–	–	–	–	–	–	–	–	–
St Lucia	–	–	–	–	–	–	–	–	–
St Vincent and the Grenadines	0.12[-7]	–	–	–	–	874[-7]	–	8.1[-7]	–
Trinidad and Tobago	0.06	0.05	0.04	0.05	–	21 309	19 232[-1]	16.1	14.4[-1]
European Union									
Austria	2.61	2.74[r]	2.68	2.81[r]	2.81[r,v]	8 860 472	10 752 629[r,v]	1 058.4	1 265.7[r,v]
Belgium	1.97	2.05	2.15	2.24[r]	2.28[v]	8 044 797	10 603 427[v]	740.6	954.9[v]
Bulgaria	0.51	0.59	0.55	0.62	0.65	548 901	742 690	73.7	102.8
Croatia	0.84	0.74	0.75	0.75	0.81	725 389	739 806	166.8	172.5
Cyprus	0.49	0.49	0.50	0.47	0.52[v]	124 114	127 783[v]	113.8	112.0[v]
Czech Rep.	1.30	1.34	1.56	1.79	1.91	3 660 339	5 812 939	349.1	543.2
Denmark	3.07	2.94	2.97	3.02	3.06[r,v]	6 717 152	7 513 404[r,v]	1 215.9	1 337.1[r,v]
Estonia	1.40	1.58	2.34	2.16	1.74	376 400	592 193	288.9	460.0
Finland	3.75	3.73	3.64	3.43	3.32	7 514 757	7 175 592	1 406.2	1 322.4[r,v]
France	2.21	2.18[s]	2.19	2.23	2.23[v]	49 757 013	55 218 177[s,v]	791.2	858.9[s,v]
Germany	2.73	2.72	2.80	2.88	2.85[r,v]	82 822 155	100 991 319[r,v]	995.7	1 220.8[r,v]
Greece	0.63[r]	0.60[r]	0.67	0.69	0.80	2 130 452[r]	2 273 861	192.0[r]	204.3
Hungary	1.14	1.15	1.20	1.27	1.41	2 382 736	3 249 569	237.5	326.4
Ireland	1.63[r]	1.62[r]	1.53[r]	1.58[r]	–	3 066 688[r]	3 271 465[-1,r]	695.3[r]	714.9[-1,r]
Italy	1.22	1.22	1.21	1.26	1.25[v]	24 648 791	26 520 408[v]	409.3	434.8[v]
Latvia	0.46	0.60	0.70	0.66	0.60	165 357	271 937	78.3	132.6
Lithuania	0.84	0.79	0.91	0.91	0.96	479 801	723 289	154.7	239.7
Luxembourg	1.72	1.50	1.41	1.16[s]	1.16[v]	683 894	571 469[s,v]	1 373.0	1 077.5[s,v]
Malta	0.54	0.68	0.72	0.90	0.89[v]	58 056	109 275[v]	137.3	254.7[v]
Netherlands	1.69	1.72	1.89[s]	1.97	1.98[v]	12 370 154	15 376 725[s,v]	746.9	917.5[s,v]
Poland	0.67	0.72	0.75	0.89	0.87	4 864 696	7 918 126	127.4	207.2
Portugal	1.58	1.53	1.46	1.37	1.36[v]	4 376 952	3 942 649[v]	413.7	371.7[v]
Romania	0.47	0.46	0.50s	0.49	0.39	1 487 584	1 480 720[s]	67.9	68.2[s]
Slovakia	0.47	0.62	0.67	0.81	0.83	592 782	1 190 627	109.3	218.5
Slovenia	1.82	2.06	2.43[s]	2.58	2.59	1 019 332	1 537 841[s]	498.6	742.2[s]
Spain	1.35	1.35	1.32	1.27	1.24	20 554 768	19 133 196	449.2	407.7
Sweden	3.42	3.22[r]	3.22	3.28[r]	3.30[q]	12 599 701	14 151 281[q]	1 353.3	1 478.5[q]
United Kingdom	1.75[r]	1.69r	1.69	1.63[r]	1.63[r,v]	39 432 832[r]	39 858 849[r,v]	639.1[r]	631.3[r,v]
South-East Europe									
Albania	0.15[-1,q]	–	–	–	–	39 832[-1,q]	–	12.6[-1,q]	–
Bosnia and Herzegovina	0.02[q]	–	–	0.27[s]	0.33	7 027[q]	119 480[s]	1.8[q]	31.2[s]
Macedonia, FYR	0.20	0.22	0.22	0.33	0.47	45 820	113 957	21.8	54.1
Montenegro	1.15[-2]	–	0.41[s]	–	0.38[s]	88 338[-2]	33 218[s]	143.0[-2]	53.5[s]
Serbia	0.87	0.74	0.72	0.91	0.73	748 598	677 967	77.2	71.3
Other Europe and West Asia									
Armenia	0.29[q]	0.24[q]	0.27[q]	0.25[q]	0.24[q]	53 140[q]	54 826[q]	17.9[q]	18.4[q]
Azerbaijan	0.25	0.22	0.21	0.22	0.21	332 970	341 284	37.1	36.3
Belarus	0.64	0.69	0.70	0.67	0.69	860 424	1 145 209	90.3	122.4
Georgia	0.18[-4]	–	–	–	0.13[s,u]	32 338[-4]	42 214[s,u]	7.2[-4]	9.7[s,u]

	R&D expenditure as percentage of GDP					R&D expenditure in current PPP$ (000s)		R&D expenditure per capita (current PPP$)	
	2009	2010	2011	2012	2013	2009	2013	2009	2013
Iran, Islamic Rep. of	0.31[i]	0.31[i]	–	–	–	3 345 394[i]	3 521 024[-3,i]	45.5[i]	47.3[-3,i]
Israel	4.15[p]	3.96[p]	4.10[p]	4.25[p]	4.21[p]	8 506 846[p]	11 032 853[p]	1 169.5[p]	1 426.7[p]
Moldova, Rep. of	0.53	0.44	0.40	0.42	0.35	66 168	58 989	18.4	16.9
Russian Federation	1.25	1.13	1.09	1.12	1.12	34 654 585	40 694 501	241.2	284.9
Turkey	0.85	0.84	0.86	0.92	0.95	8 867 131	13 315 099	124.5	177.7
Ukraine	0.86	0.83	0.74	0.75	0.77	2 867 129	3 067 360	62.0	67.8
European Free Trade Assoc.									
Iceland	2.66	–	2.49[s]	–	–	337 939	314 837[-2,s]	1 076.9	977.6[-2,s]
Liechtenstein	–	–	–	–	–	–	–	–	–
Norway	1.76	1.68	1.65	1.65	1.69	4 676 887	5 519 606	967.2	1 094.6
Switzerland	2.73[-1]	–	–	2.96	–	10 525 201[-1]	13 251 396[-1]	1 375.3[-1]	1 657.0[-1]
Sub–Saharan Africa									
Angola	–	–	–	–	–	–	–	–	–
Benin	–	–	–	–	–	–	–	–	–
Botswana	0.53[-4]	–	–	0.26[s]	–	102 226[-4]	76 096[-1,s]	54.5[-4]	38.0[-1,s]
Burkina Faso	0.20	–	–	–	–	39 877	–	2.6	–
Burundi	0.14[q]	0.14[q]	0.12[q]	–	–	9 014[q]	8 460[-2,q]	1.0[q]	0.9[-2,q]
Cabo Verde	–	–	0.07[l,q]	–	–	–	2 211[-2,l,q]	–	4.5[-2,l,q]
Cameroon	–	–	–	–	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	–	–	–	–
Congo	–	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of	0.08[k,u]	–	–	–	–	30 743[k,u]	–	0.5[k,u]	–
Côte d'Ivoire	–	–	–	–	–	–	–	–	–
Djibouti	–	–	–	–	–	–	–	–	–
Equatorial Guinea	–	–	–	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–	–	–	–
Ethiopia	0.17[-2,q]	0.24[s]	–	–	0.61	111 769[-2,q]	787 350[s]	1.4[-2,q]	8.4[s]
Gabon	0.58	–	–	–	–	137 154	–	90.3	–
Gambia	0.02[q]	–	0.13[b]	–	–	445[q]	3 544[-2,b]	0.3[q]	2.0[-2,b]
Ghana	0.23[-2]	0.38[s]	–	–	–	133 220[-2]	274 351[-3,s]	5.9[-2]	11.3[-3,s]
Guinea	–	–	–	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–	–
Kenya	0.36[-2,q]	0.79[s]	–	–	–	305 213[-2,q]	788 126[-3,s]	8.1[-2,q]	19.3[-3,s]
Lesotho	0.03[q]	–	0.01[l,q]	–	–	1 200[q]	599[-2,l,q]	0.6[q]	0.3[-2,l,q]
Liberia	–	–	–	–	–	–	–	–	–
Madagascar	0.15[q]	0.11[q,s]	0.11[q]	–	–	41 544[q]	31 484[-2,q,s]	2.0[q]	1.5[-2,q,s]
Malawi	–	–	–	–	–	–	–	–	–
Mali	0.25[-2,i,q]	0.66[h]	–	–	–	47 068[-2,i,q]	150 785[-3,h]	3.7[-2,i,q]	10.8[-3,h]
Mauritius	0.37[-4,b,u]	–	–	0.18[h,s]	–	51 912[-4,b,u]	38 584[-1,h,s]	42.8[-4,b,u]	31.1[-1,h,s]
Mozambique	0.16[-1,h,j,q]	0.42[h,s]	–	–	–	30 012[-1,h,j,q]	92 445[-3,h,s]	1.3[-1,h,j,q]	3.9[-3,h,s]
Namibia	–	0.14[i,q]	–	–	–	–	25 516[-3,i,q]	–	11.7[-3,i,q]
Niger	–	–	–	–	–	–	–	–	–
Nigeria	0.22[-2,h]	–	–	–	–	1 374 841[-2,h]	–	9.3[-2,h]	–
Rwanda	–	–	–	–	–	–	–	–	–
Sao Tome and Principe	–	–	–	–	–	–	–	–	–
Senegal	0.37[-1]	0.54	–	–	–	93 586[-1]	149 726[-3]	7.6[-1]	11.6[-3]
Seychelles	0.30[-4]	–	–	–	–	3 955[-4]	–	45.4[-4]	–
Sierra Leone	–	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–	–
South Africa	0.84	0.74	0.73	0.73	–	4 818 930	4 824 364[-1]	94.7	92.1[-1]
South Sudan	–	–	–	–	–	–	–	–	–
Swaziland	–	–	–	–	–	–	–	–	–
Tanzania	0.34[-2,h,q]	0.38[h,q]	–	–	–	251 377[-2,h,q]	348 185[-3,h,q]	6.1[-2,h,q]	7.7[-3,h,q]
Togo	–	0.25[h]	–	0.22[h]	–	–	19 622[-1,h]	–	3.0[-1,h]
Uganda	0.36	0.48	–	–	–	170 176	240 005[-3]	5.2	7.1[-3]
Zambia	0.28[-1]	–	–	–	–	101 149[-1]	–	8.1[-1]	–
Zimbabwe	–	–	–	–	–	–	–	–	–
Arab states									
Algeria	0.07[-4,q]	–	–	–	–	241 164[-4,q]	–	7.1[-4,q]	–
Bahrain	0.04[l,q]	0.04[l,q]	0.04[l,q]	0.04[l,q]	0.04[l,q]	18 124[l,q]	24 516[l,q]	15.2[l,q]	18.4[l,q]
Egypt	0.43[h]	0.43[h]	0.53[h]	0.54[h]	0.68[h]	3 306 085[h]	6 169 203[h]	43.1[h]	75.2[h]
Iraq	0.05[h,u]	0.04[h,u]	0.03[h,u]	–	–	159 710[h,u]	146 269[-2,h,u]	5.3[h,u]	4.6[-2,h,u]
Jordan	0.43[-1]	–	–	–	–	263 201[-1]	–	44.5[-1]	–
Kuwait	0.11[k,q]	0.10[k,q]	0.10[k,q]	0.10[k,q]	0.30[h,s]	249 477[k,q]	264 911[-1,k,q]	87.5[k,q]	81.5[-1,k,q]
Lebanon	–	–	–	–	–	–	–	–	–
Libya	–	–	–	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–	–	–	–
Morocco	0.64[-3]	0.73	–	–	–	1 030 143[-3]	1 494 848[-3]	33.9[-3]	47.2[-3]
Oman	–	–	0.13[r]	0.21	0.17	–	309 780[-1]	–	93.5[-1]
Palestine	–	–	–	–	–	–	–	–	–
Qatar	–	–	–	0.47	–	–	1 296 303[-1]	–	632.2[-1]
Saudi Arabia	0.07[q]	–	–	–	–	832 203[q]	–	31.1[q]	–
Sudan	0.30[-4,b,r]	–	–	–	–	298 413[-4,b,r]	–	9.4[-4,b,r]	–
Syrian Arab Rep.	–	–	–	–	–	–	–	–	–
Tunisia	0.71	0.68	0.71	0.68	–	728 030	790 712[-1]	69.3	72.7[-1]
United Arab Emirates	–	–	0.49[r]	–	–	–	2 461 027[-2,r]	–	275.7[-2,r]
Yemen	–	–	–	–	–	–	–	–	–

Table S3: R&D expenditure as a share of GDP and in purchasing power parity (PPP) dollars, 2009-2013

	R&D expenditure as percentage of GDP					R&D expenditure in current PPP$ (000s)		R&D expenditure per capita (current PPP$)	
	2009	2010	2011	2012	2013	2009	2013	2009	2013
Central Asia									
Kazakhstan	0.23	0.15	0.16	0.17	0.17	661 567	691 400	42.0	42.1
Kyrgyzstan	0.16	0.16	0.16	–	–	23 648	25 179[-2]	4.5	4.7[-2]
Mongolia	0.30[q]	0.28[q]	0.27[q]	0.28[q]	0.25[q]	48 720[q]	68 029[q]	18.2[q]	24.0[q]
Tajikistan	0.09[h]	0.09[h]	0.12[h]	0.11[h]	0.12[h]	12 546[h]	24 269[h]	1.7[h]	3.0[h]
Turkmenistan	–	–	–	–	–	–	–	–	–
Uzbekistan	–	–	–	–	–	–	–	–	–
South Asia									
Afghanistan	–	–	–	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–	–	–	–
India	0.82	0.80[r]	0.82[r]	–	–	39 400 485	48 062 976[-2,r]	33.1	39.4[-2,r]
Maldives	–	–	–	–	–	–	–	–	–
Nepal	0.26[q,u]	0.30[q,u]	–	–	–	128 477[q,u]	158 906[-3,q,u]	4.8[q,u]	5.9[-3,q,u]
Pakistan	0.45[h]	–	0.33[h]	–	0.29[h]	3 118 457[h]	2 443 292[h]	18.3[h]	13.4[h]
Sri Lanka	0.11[-1]	0.16	–	–	–	153 681[-1]	240 005[-3]	7.5[-1]	11.6[-3]
South–East Asia									
Brunei Darussalam	0.04[-5,q]	–	–	–	–	8 708[-5,q]	–	24.1[-5,q]	–
Cambodia	0.05[-7,q,r]	–	–	–	–	7 901[-7,q,r]	–	0.6[-7,q,r]	–
China	1.70	1.76	1.84	1.98	2.08	184 170 641	336 577 729	136.3	242.9
China, Hong Kong SAR	0.77	0.75	0.72	0.73	–	2 369 983	2 663 088[-1]	338.2	372.5[-1]
China, Macao SAR	0.05[q]	0.05[q]	0.04[q]	0.05[q]	0.05[q]	21 945[q]	41 151[q]	42.1[q]	72.7[q]
Indonesia	0.08[q,r]	–	–	–	0.09[r]	1 466 763[q,r]	2 126 345[r]	6.2[q,r]	8.5[r]
Japan	3.36	3.25	3.38	3.34	3.47	136 953 957	160 246 832	1 075.4	1 260.4
Korea, DPR	–	–	–	–	–	–	–	–	–
Korea, Rep. of	3.29	3.47	3.74	4.03	4.15	45 987 242	68 937 037	954.8	1 399.4
Lao PDR	0.04[-7,q]	–	–	–	–	4 289[-7,q]	–	0.8[-7,q]	–
Malaysia	1.01	1.07	1.06	1.13	–	5 248 826	7 351 372[-1]	188.9	251.4[-1]
Myanmar	0.16[-7,q]	–	–	–	–	–	–	–	–
Philippines	0.11[-2]	–	–	–	–	477 841[-2]	–	5.4[-2]	–
Singapore	2.16	2.01	2.16	2.02	–	6 612 088	8 152 867[-1]	1 331.9	1 537.3[-1]
Thailand	0.25	–	0.39	–	–	1 915 168	3 303 858[-2]	28.9	49.6[-2]
Timor–Leste	–	–	–	–	–	–	–	–	–
Viet Nam	0.18[-7]	–	0.19	–	–	340 429[-7]	789 059[-2]	4.1[-7]	8.8[-2]
Oceania									
Australia	2.40[-1]	2.39[r]	2.25[r]	–	–	19 132 997[-1]	20 955 599[-2,r]	883.9[-1]	921.5[-2,r]
New Zealand	1.28	–	1.27	–	–	1 655 439	1 766 588[-2]	382.9	400.2[-2]
Cook Islands	–	–	–	–	–	–	–	–	–
Fiji	–	–	–	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–	–	–	–
Nauru	–	–	–	–	–	–	–	–	–
Niue	–	–	–	–	–	–	–	–	–
Palau	–	–	–	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–	–	–	–
Samoa	–	–	–	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–	–	–	–
Tonga	–	–	–	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–	–	–	–

Note: UNESCO Institute for Statistics (UIS), August, 2015

Sources for background data:
GDP and PPP conversion factor (local currency per international $): World Bank; World Development Indicators, as of April 2015.
Population: United Nations, Department of Economic and Social Affairs, Population Division, 2013; *World Population Prospects: The 2012 Revision*

N.B.: See Key To All Tables at the end of Table S10.

Table S4: Public expenditure on tertiary education, 2008 and 2013

	Public expenditure on tertiary education as % of GDP		Public expenditure per tertiary student as % of GDP per capita		Public expenditure on tertiary education as % of total public expenditure on education	
	2008	2013	2008	2013	2008	2013
North America						
Canada	1.61	1.88^{-2}	–	–	34.44	35.60^{-2}
United States of America	1.24	1.36^{-2}	20.43	20.08^{-2}	23.33	26.11^{-2}
Latin America						
Argentina	0.77	1.02^{-1}	13.29	15.44^{-1}	17.66	19.94^{-1}
Belize	0.52	0.59^{-1}	25.90	22.66^{-1}	9.19	–
Bolivia	2.05	1.61^{-1}	–	–	29.09	25.00^{-1}
Brazil	0.86	1.04^{-1}	27.67	28.49^{-1}	15.91	16.37^{-1}
Chile	0.55	0.96^{-1}	11.51	15.01^{-1}	14.51	21.12^{-1}
Colombia	0.86	0.87	26.17	20.01	22.05	17.73
Costa Rica	–	1.43	–	33.83	–	20.75
Ecuador	1.08^{+2}	1.11^{-1}	–	–	26.58^{+2}	26.66^{-1}
El Salvador	0.42^{+1}	0.29^{-2}	17.85^{+1}	11.18^{-2}	10.46^{+1}	8.39^{-2}
Guatemala	0.34	0.35	–	18.43	10.80	12.30
Guyana	0.25^{+1}	0.16^{-1}	27.06^{+1}	14.52^{-1}	7.34^{+1}	5.06^{-1}
Honduras	0.89^{+2}	1.08	39.92^{+2}	47.74	–	18.49
Mexico	0.92	0.93^{-2}	40.16	37.34^{-2}	18.86	18.13^{-2}
Nicaragua	1.14^{+2}	1.14^{-3}	–	–	26.05^{+2}	26.05^{-3}
Panama	–	0.74^{-1}	–	20.13^{-1}	–	–
Paraguay	0.70^{+2}	1.11^{-1}	20.03^{+2}	–	18.54^{+2}	22.40^{-1}
Peru	0.45	0.55	–	–	15.71	16.82
Suriname	–	–	–	–	–	–
Uruguay	–	1.19^{-2}	–	–	–	26.83^{-2}
Venezuela	1.55^{+1}	–	20.92^{+1}	–	22.60^{+1}	–
Caribbean						
Antigua and Barbuda	0.19^{+1}	–	15.63^{+1}	–	7.35^{+1}	–
Bahamas	–	–	–	–	–	–
Barbados	1.53	2.08	–	–	30.09	–
Cuba	5.34	4.47^{-3}	61.10	62.99^{-3}	37.98	34.83^{-3}
Dominica	–	–	–	–	–	–
Dominican Rep.	–	–$^{-1}$	–	–$^{-1}$	–	–$^{-1}$
Grenada	–	–	–	–	–	–
Haiti	–	–	–	–	–	–
Jamaica	0.97	1.10	42.38	40.09	15.71	17.61
St Kitts and Nevis	–	–	–	–	–	–
St Lucia	0.24^{+1}	0.21^{-2}	14.66^{+1}	14.54^{-2}	6.30^{+1}	5.01^{-2}
St Vincent and the Grenadines	0.31^{+1}	0.36^{-3}	–	–	5.42^{+1}	7.01^{-3}
Trinidad and Tobago	–	–	–	–	–	–
European Union						
Austria	1.44	1.51^{-2}	42.09	35.00^{-2}	27.19	26.86^{-2}
Belgium	1.34	1.43^{-1}	35.66	33.33^{-1}	21.32	22.00^{-2}
Bulgaria	0.84	0.62^{-2}	23.70	16.04^{-2}	19.40	16.98^{-2}
Croatia	0.94	0.92^{-2}	28.99	25.61^{-2}	21.96	22.16^{-2}
Cyprus	1.85	1.48^{-2}	57.03	39.23^{-2}	24.99	20.45^{-2}
Czech Rep.	0.89	1.11^{-2}	23.54	26.00^{-2}	23.71	25.79^{-2}
Denmark	2.12	2.39^{-2}	50.50	51.31^{-2}	28.30	27.90^{-2}
Estonia	1.10	1.28^{-2}	21.51	24.56^{-2}	19.87	25.09^{-2}
Finland	1.81	2.06^{-1}	31.11	36.14^{-1}	31.00	28.56^{-1}
France	1.21	1.23^{-1}	35.94	35.28^{-1}	22.20	22.34^{-1}
Germany	1.18	1.35^{-2}	–	–	26.65	28.13^{-2}
Greece	–	–	–	–	–	–
Hungary	1.01	0.80^{-1}	24.39	20.93^{-1}	20.01	23.39^{-2}
Ireland	1.27	1.27^{-2}	32.00	29.64^{-2}	23.26	21.73^{-2}
Italy	0.81	0.80^{-2}	23.56	24.19^{-2}	18.33	19.36^{-2}
Latvia	0.99	0.95^{-1}	16.88	19.93^{-1}	17.33	20.72^{-1}
Lithuania	1.03	1.47^{-2}	16.15	23.82^{-2}	21.20	28.45^{-2}
Luxembourg	–	–	–	–	–	–
Malta	1.03	1.50^{-1}	44.71	51.52^{-1}	17.69	22.17^{-1}
Netherlands	1.42	1.59^{-1}	38.82	33.51^{-1}	27.77	28.79^{-1}
Poland	1.04	1.11^{-2}	18.35	20.55^{-2}	20.54	22.82^{-2}
Portugal	0.91	1.01^{-2}	25.47	26.88^{-2}	19.34	19.70^{-2}
Romania	1.20^{+1}	0.78^{-1}	22.24^{+1}	–	28.28^{+1}	26.16^{-1}
Slovakia	0.76	0.94^{-1}	17.89	23.08^{-1}	21.53	23.98^{-1}
Slovenia	1.19	1.35^{-2}	20.83	25.83^{-2}	23.30	24.20^{-2}
Spain	1.04	0.97^{-1}	26.80	23.18^{-1}	23.08	22.31^{-1}
Sweden	1.73	1.89^{-2}	39.11	38.47^{-2}	27.01	29.08^{-2}
United Kingdom	0.80	1.27^{-2}	21.18	32.01^{-2}	15.71	22.10^{-2}
South-East Europe						
Albania	–	–	–	–	–	–
Bosnia and Herzegovina	–	–	–	–	–	–
Macedonia, FYR	–	–	–	–	–	–
Montenegro	–	–	–	–	–	–
Serbia	1.29	1.29^{-1}	39.75	40.06^{-1}	27.30	29.12^{-1}
Other Europe and West Asia						
Armenia	0.36	0.20	7.54	5.07	11.29	8.72
Azerbaijan	0.28	0.36^{-2}	13.45	18.05^{-2}	11.34	14.63^{-2}
Belarus	0.91^{+1}	0.93	15.56^{+1}	15.62	20.07^{+1}	17.58
Georgia	0.34	0.38^{-1}	11.40	17.18^{-1}	11.58	19.17^{-1}

Table S4: Public expenditure on tertiary education, 2008 and 2013

	Public expenditure on tertiary education as % of GDP		Public expenditure per tertiary student as % of GDP per capita		Public expenditure on tertiary education as % of total public expenditure on education	
	2008	2013	2008	2013	2008	2013
Iran, Islamic Rep. of	0.99	0.84	20.95	14.77	20.67	22.94
Israel	0.89	0.91[-2]	20.10	19.41[-2]	16.00	16.22[-2]
Moldova, Rep. of	1.54	1.47[-1]	38.18	41.83[-1]	18.65	17.56[-1]
Russian Federation	0.95	–	14.25	–	23.11	–
Turkey	–	–	–	–	–	–
Ukraine	2.03	2.16[-1]	32.93	41.17[-1]	31.53	32.41[-1]
European Free Trade Assoc.						
Iceland	1.42	1.37[-2]	27.17	23.17[-2]	19.70	19.42[-2]
Liechtenstein	–	–	–	–	–	–
Norway	2.05	1.96[-2]	45.91	42.23[-2]	31.99	29.89[-2]
Switzerland	1.27[+1]	1.33[-1]	42.19[+1]	39.40[-1]	25.14[+1]	26.31[-1]
Sub–Saharan Africa						
Angola	–	–	–	–	–	–
Benin	0.72	1.05	102.67	–	17.64	21.04
Botswana	3.94[+1]	–	159.02[+1]	–	41.51[+1]	–
Burkina Faso	0.74[+2]	0.93	225.08[+2]	210.92	18.84[+2]	21.72
Burundi	1.10	1.31	434.66	297.08	21.21	24.23
Cabo Verde	0.62	0.78	45.28	29.76	11.27	15.82
Cameroon	0.26	0.23[-1]	34.74	–	8.85	7.77[-1]
Central African Rep.	0.23	0.34[-2]	99.63	111.93[-2]	17.48	27.29[-2]
Chad	0.29[+1]	0.37[-2]	159.53[+1]	182.41[-2]	12.38[+1]	16.28[-2]
Comoros	1.14	–	–	–	14.61	–
Congo	0.68[+2]	0.71	–	84.71	10.87[+2]	–
Congo, Dem. Rep. of	0.37[+2]	0.37[-3]	–	–	24.00[+2]	24.00[-3]
Côte d'Ivoire	–	–	–	–	–	–
Djibouti	0.74[+2]	0.74[-3]	191.60[+2]	191.60[-3]	16.50[+2]	16.50[-3]
Equatorial Guinea	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–
Ethiopia	0.16[+2]	0.16[-3]	24.21[+2]	24.21[-3]	3.54[+2]	3.54[-3]
Gabon	–	–	–	–	–	–
Gambia	0.32	0.30[-1]	–	–	9.03	7.36[-1]
Ghana	1.49	1.07[-2]	180.80	92.78[-2]	25.85	13.13[-2]
Guinea	0.84	1.23	107.93	131.61	34.42	34.64
Guinea–Bissau	–	–	–	–	–	–
Kenya	–	–	–	–	–	–
Lesotho	4.72	–	–	–	36.38	–
Liberia	–	0.10[-1]	–	9.34[-1]	–	3.56[-1]
Madagascar	0.45	0.29	143.53	67.49	15.36	13.74
Malawi	1.30[+2]	2.18	–	–	29.80[+2]	28.36
Mali	0.61	0.85[-1]	118.71	130.04[-1]	16.06	20.34[-1]
Mauritius	0.33	0.29	15.85	8.92	10.21	8.02
Mozambique	–	0.91	–	183.43	–	13.69
Namibia	0.64	1.93[-3]	–	–	9.91	23.09[-3]
Niger	0.34	0.80[-1]	396.20	631.00[-1]	9.41	17.61[-1]
Nigeria	–	–	–	–	–	–
Rwanda	0.96	0.71	217.70	104.75	25.41	14.02
Sao Tome and Principe	–	–	–	–	–	–
Senegal	1.24	1.38[-3]	166.00	193.48[-3]	24.55	24.57[-3]
Seychelles	–	1.18[-2]	–	545.71[-2]	–	32.51[-2]
Sierra Leone	0.50	0.73	–	–	20.83	25.93
Somalia	–	–	–	–	–	–
South Africa	0.63	0.74	–	38.73	13.01	12.41
South Sudan	–	0.20[-2]	–	–	–	25.34[-2]
Swaziland	1.62	1.01[-2]	–	–	21.55	12.84[-2]
Tanzania	1.27	0.76[+1]	–	–	29.85	21.40[+1]
Togo	0.69	0.98	–	102.75	20.10	22.21
Uganda	0.37[+1]	0.30	108.51[+1]	–	11.30[+1]	13.76
Zambia	–	–	–	–	–	–
Zimbabwe	0.27[+1]	0.45[-3]	–	62.00[-3]	–	22.82[-3]
Arab states						
Algeria	1.17	–	–	–	26.97	–
Bahrain	–	0.60	–	–	–	–
Egypt	–	–	–	–	–	–
Iraq	–	–	–	–	–	–
Jordan	–	–	–	–	–	–
Kuwait	–	–	–	–	–	–
Lebanon	0.59	0.74	12.55	15.55	28.98	28.74
Libya	–	–	–	–	–	–
Mauritania	0.67	0.46	190.41	93.30	16.72	11.58
Morocco	0.90	1.11	70.73	–	16.23	17.70
Oman	1.13[+1]	–	39.60[+1]	–	26.88[+1]	–
Palestine	–	–	–	–	–	–
Qatar	–	–	–	–	–	–
Saudi Arabia	–	–	–	–	–	–
Sudan	–	–	–	–	–	–
Syrian Arab Rep.	1.15	1.24[-4]	44.77	49.00[-4]	24.94	24.22[-4]
Tunisia	1.57	1.75	–	56.59	25.00	–
United Arab Emirates	–	–	–	–	–	–
Yemen	–	–	–	–	–	–

	Public expenditure on tertiary education as % of GDP		Public expenditure per tertiary student as % of GDP per capita		Public expenditure on tertiary education as % of total public expenditure on education	
	2008	2013	2008	2013	2008	2013
Central Asia						
Kazakhstan	0.36	0.40^{-4}	–	–	13.90	13.13^{-4}
Kyrgyzstan	0.97	0.89^{-1}	19.04	–	16.44	12.03^{-1}
Mongolia	0.36^{+2}	0.21^{-2}	5.89^{+2}	3.37^{-2}	6.68^{+2}	3.83^{-2}
Tajikistan	0.49	0.46	18.93	19.33	14.25	–
Turkmenistan	–	0.28^{-1}	–	–	–	9.23^{-1}
Uzbekistan	–	–	–	–	–	–
South Asia						
Afghanistan	–	–	–	–	–	–
Bangladesh	0.27	0.23^{-2}	30.83	17.44^{-2}	13.26	–
Bhutan	0.93	1.02	150.89	102.12	19.40	18.23
India	1.17^{+1}	1.28^{-1}	74.31^{+1}	54.88^{-1}	36.45^{+1}	33.19^{-1}
Maldives	–	0.58^{-1}	–	–	–	9.35^{-1}
Nepal	0.51	0.50^{-3}	46.63	35.39^{-3}	13.46	10.65^{-3}
Pakistan	–	0.80	–	75.18	–	32.23
Sri Lanka	0.37^{+1}	0.32^{-1}	–	24.19^{-1}	18.19^{+1}	18.73^{-1}
South–East Asia						
Brunei Darussalam	0.50^{+2}	1.20^{+1}	32.22^{+2}	57.09^{+1}	24.38^{+2}	31.92^{+1}
Cambodia	0.38^{+2}	0.38^{-3}	27.83^{+2}	27.83^{-3}	14.54^{+2}	14.54^{-3}
China	–	–	–	–	–	–
China, Hong Kong SAR	1.02	1.16^{-1}	27.81	30.37^{-1}	31.16	33.02^{-1}
China, Macao SAR	0.82	2.28^{-1}	16.30	49.03^{-1}	36.64	68.14^{-1}
Indonesia	0.32	0.61^{-1}	16.89	24.27^{-1}	10.98	17.18^{-1}
Japan	0.65	0.76	21.09	–	18.86	20.00
Korea, DPR	–	–	–	–	–	–
Korea, Rep. of	0.62	0.86	9.49	–	13.92	–
Lao PDR	–	–	–	–	–	–
Malaysia	2.15^{+1}	2.19^{-2}	59.63^{+1}	60.88^{-2}	35.94^{+1}	36.97^{-2}
Myanmar	–	–	–	–	–	–
Philippines	0.28	0.32^{-4}	9.66	10.51^{-4}	10.42	11.96^{-4}
Singapore	0.91	1.04	–	22.59	32.59	35.28
Thailand	0.79	0.71^{-1}	21.63	19.52^{-1}	21.18	14.42^{-1}
Timor–Leste	0.93^{+1}	1.87^{-2}	58.52^{+1}	–	8.14^{+1}	19.79^{-2}
Viet Nam	1.08	1.05^{-1}	55.71	41.24^{-1}	22.16	16.67^{-1}
Oceania						
Australia	1.04	1.18^{-2}	19.78	19.99^{-2}	22.46	23.20^{-2}
New Zealand	1.62	1.86^{-1}	27.94	31.46^{-1}	28.92	25.33^{-1}
Cook Islands	–	a^{-}	–	a^{-}	–	a^{-}
Fiji	–	0.56^{-2}	–	–	–	12.96^{-2}
Kiribati	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–
Nauru	–	–	–	–	–	–
Niue	–	–	–	–	–	–
Palau	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–
Samoa	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–
Tonga	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–
Vanuatu	0.34	–	–	–	5.86	–

Source: UNESCO Institute for Statistics

N.B.: See key to all tables at the end of Table S10.

Table S5: Tertiary graduates in 2008 and 2013 and graduates in science, engineering, agriculture and health in 2013

	2008		2013					
	Tertiary graduates		Tertiary graduates		Science			
	MF (000s)	Females (%)	MF (000s)	Females (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
North America								
Canada	–	–	–	–	–	–	–	–
United States of America	2 782.27	58.5	3 308.49^{-1}	58.4^{-1}	41.14^{-1}	235.23^{-1}	16.67^{-1}	40.94^{-1}
Latin America								
Argentina	235.86	65.7	123.24^{-1}	60.8^{-1}	9.07^{-2}	5.65^{-2}	0.73^{-2}	–
Belize	–	–	–	–	0.30	–	a	a
Bolivia	–	–	–	–	–	–	–	–
Brazil	917.11	60.3	1 111.46^{-1}	60.8^{-1}	18.30^{-1}	40.10^{-1}	–	–
Chile	92.23	54.0	147.55^{-1}	56.0^{-1}	4.29^{-1}	2.82^{-1}	0.24^{-1}	40.00^{-1}
Colombia	134.92	42.6	344.07	55.3	9.06	5.36	0.08	35.44
Costa Rica	38.16^{+2}	63.3^{+2}	44.58	63.2	0.28	2.34	0.01	42.86
Ecuador	70.19	58.8	79.19^{-1}	58.5^{-1}	1.54^{-1}	–	0^{-1}	a^{-1}
El Salvador	15.80	58.2	23.62	56.6	0	0.24	0	a
Guatemala	–	–	20.83	58.3	–	–	–	–
Guyana	1.75	70.0	1.84^{-1}	74.9^{-1}	0^{-1}	0.11^{-1}	a^{-1}	a^{-1}
Honduras	15.41^{+2}	–	18.67	63.1	0.01	0.52	a	a
Mexico	420.48	54.3	533.87^{-1}	53.5^{-1}	0.50^{-1}	28.29^{-1}	0.79^{-1}	46.56^{-1}
Nicaragua	–	–	–	–	–	–	–	–
Panama	21.06	66.0	22.79^{-1}	65.4^{-1}	0.27^{-1}	–	0^{-1}	a^{-1}
Paraguay	–	–	–	–	0.18^{-1}	–	–	–
Peru	–	–	–	–	14.00^{-1}	–	–	–
Suriname	–	–	–	–	–	–	–	–
Uruguay	9.47	65.1	–	–	0.02^{-3}	0.55^{-3}	0.03^{-3}	66.67^{-3}
Venezuela	–	–	–	–	–	–	–	–
Caribbean								
Antigua and Barbuda	0.15^{+1}	77.0^{+1}	0.25^{-1}	87.8^{-1}	0.01^{-1}	0.00^{-1}	0^{-1}	a^{-1}
Bahamas	–	–	–	–	–	–	–	–
Barbados	2.26^{+2}	–	2.39^{-2}	68.4^{-2}	0.13^{-2}	0.18^{-2}	0.00^{-2}	100.00^{-2}
Cuba	103.76	47.9	133.29	62.6	a	3.57	0.08	39.74
Dominica	–	–	–	–	–	–	–	–
Dominican Rep.	–	–	41.11^{-1}	64.1^{-1}	0.00^{-1}	–	a^{-1}	a^{-1}
Grenada	–	–	–	–	–	–	–	–
Haiti	–	–	–	–	–	–	–	–
Jamaica	–	–	–	–	–	–	–	–
St Kitts and Nevis	–	–	–	–	–	–	–	–
St Lucia	–	–	0.58	–	0	–	a	a
St Vincent and the Grenadines	–	–	–	–	–	–	–	–
Trinidad and Tobago	–	–	–	–	–	–	–	–
European Union								
Austria	43.65	51.6	85.28	56.0	1.12	5.97	0.60	35.93
Belgium	97.25	58.7	110.42^{-1}	59.3^{-1}	1.55^{-1}	3.82^{-1}	0.52^{-1}	34.87^{-1}
Bulgaria	54.91	61.4	64.09^{-1}	60.8^{-1}	0.06^{-1}	2.91^{-1}	0.16^{-1}	52.90^{-1}
Croatia	26.94	58.4	39.82^{-1}	59.3^{-1}	0.73^{-1}	2.38^{-1}	0.24^{-1}	60.25^{-1}
Cyprus	4.23	61.6	6.17^{-1}	60.3^{-1}	0.09^{-1}	0.41^{-1}	0.02^{-1}	52.63^{-1}
Czech Rep.	88.98	58.1	107.77^{-1}	62.2^{-1}	0.30^{-1}	9.07^{-1}	0.72^{-1}	39.97^{-1}
Denmark	49.75	57.8	66.47	57.5	0.46	4.70	0.34	35.22
Estonia	11.35	69.3	11.44^{-1}	67.5^{-1}	0.19^{-1}	0.90^{-1}	0.08^{-1}	52.63^{-1}
Finland	43.01^{+1}	62.8^{+1}	52.73	60.1	0	3.42	0.34	39.35
France	628.09	54.9	726.54	56.1	6.22	55.64	6.50	40.01
Germany	–	–	–	–	–	–	–	–
Greece	66.96	59.3	66.33^{-1}	59.1^{-1}	1.64^{-1}	6.24^{-1}	0.29^{-1}	33.33^{-1}
Hungary	63.33	66.8	69.92^{-1}	64.0^{-1}	0.60^{-1}	3.47^{-1}	0.29^{-1}	37.54^{-1}
Ireland	60.07	56.3	60.02^{-1}	54.5^{-1}	1.40^{-1}	5.23^{-1}	0.51^{-1}	45.12^{-1}
Italy	398.19	59.5	374.99^{-1}	62.3^{-1}	0^{-1}	24.97^{-1}	2.69^{-1}	52.58^{-1}
Latvia	24.17	71.5	21.61	69.0	0.18	1.04	0.07	54.41
Lithuania	42.55	66.7	39.27	63.3	a	2.05	0.08	49.35
Luxembourg	0.34	49.4	1.57	53.6	0.00	0.13	0.03	32.00
Malta	2.79	59.4	3.46^{-1}	57.4^{-1}	0.15^{-1}	0.22^{-1}	0.00^{-1}	0^{-1}
Netherlands	124.23	56.7	152.05^{-1}	56.5^{-1}	0.01^{-1}	8.64^{-1}	0.83^{-1}	33.41^{-1}
Poland	558.02	65.8	638.96^{-1}	66.0^{-1}	a	38.20	–	–
Portugal	84.01	59.6	94.87	59.8	a	6.57	0.93	54.03
Romania	311.48	63.7	259.63^{-2}	61.6^{-2}	a^{-2}	12.56^{-2}	0.52^{-2}	53.74^{-2}
Slovakia	65.03	64.2	70.03	63.6	0.01	4.81	0.34	53.35
Slovenia	17.22	62.8	20.60^{-1}	60.3^{-1}	0.23^{-1}	1.29^{-1}	0.15^{-1}	38.96^{-1}
Spain	291.04	58.4	391.96^{-1}	56.2^{-1}	4.10^{-1}	23.27^{-1}	3.48^{-1}	47.42^{-1}
Sweden	60.43	63.5	69.14^{-1}	61.6^{-1}	0.66^{-1}	4.24^{-1}	0.87^{-1}	41.64^{-1}
United Kingdom	676.20	57.9	791.95	57.1	14.70	105.01	8.49	45.59
South-East Europe								
Albania	15.65	64.4	30.37	65.0	a	2.13	0.04	44.19
Bosnia and Herzegovina	15.77	58.7	21.21	60.0	a	1.41	0.01	25.00
Macedonia, FYR	11.20	59.7	11.36	56.3	a	1.15	0.02	56.25
Montenegro	–	–	–	–	–	–	–	–
Serbia	36.33	60.4	47.80	58.4	a	4.73	0.12	58.33

2013											
Engineering, manufacturing and construction				Agriculture				Health and welfare			
Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
–	–	–	–	–	–	–	–	–	–	–	–
66.85^{-1}	161.86^{-1}	9.11^{-1}	23.33^{-1}	8.52^{-1}	25.05^{-1}	0.99^{-1}	44.31^{-1}	227.17^{-1}	330.11^{-1}	16.09^{-1}	72.64^{-1}
5.72^{-2}	8.68^{-2}	0.09^{-2}	45.45^{-2}	1.50^{-2}	3.27^{-2}	0.08^{-2}	–	20.66^{-2}	18.68^{-2}	0.12^{-2}	55.65^{-2}
0	–	a	a	0.02	–	a	a	0	–	a	a
–	–	–	–	–	–	–	–	–	–	–	–
13.60^{-1}	60.94^{-1}	–	–	2.09^{-1}	16.75^{-1}	–	–	2.76^{-1}	158.82^{-1}	–	–
11.99^{-1}	9.22^{-1}	0.08^{-1}	37.18^{-1}	1.28^{-1}	2.31^{-1}	0.04^{-1}	34.09^{-1}	17.22^{-1}	14.34^{-1}	0.03^{-1}	34.38^{-1}
21.16	38.50	0.07	17.57	3.84	2.48	0.02	47.06	6.23	19.35	0.03	67.65
0.14	2.78	0	a	0.10	0.60	0.00	0	0.07	6.32	0	a
1.53^{-1}	–	0^{-1}	a^{-1}	0.32^{-1}	–	0^{-1}	a^{-1}	1.17^{-1}	–	0^{-1}	a^{-1}
2.70	2.31	0	a	0.14	0.19	0	a	1.66	2.36	0	a
–	–	–	–	–	–	–	–	–	–	–	–
0.14^{-1}	0^{-1}	a^{-1}	a^{-1}	0.03^{-1}	0^{-1}	a^{-1}	a^{-1}	0.25^{-1}	0^{-1}	a^{-1}	a^{-1}
0.04	2.11	a	a	0.05	0.59	a	a	0.08	1.29	a	a
18.11^{-1}	95.23^{-1}	0.60^{-1}	39.53^{-1}	0.08^{-1}	8.70^{-1}	0.22^{-1}	46.33^{-1}	1.72^{-1}	46.32^{-1}	0.09^{-1}	61.29^{-1}
–	–	–	–	–	–	–	–	–	–	–	–
0.60^{-1}	–	0.00^{-1}	75.00^{-1}	0.04^{-1}	–	0^{-1}	a^{-1}	0.47^{-1}	–	0^{-1}	a^{-1}
0.01^{-1}	–	–	–	0.02^{-1}	–	–	–	0.21^{-1}	–	–	–
10.58^{-1}	–	–	–	3.71^{-1}	–	–	–	20.90^{-1}	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
0.02^{-3}	0.57^{-3}	0.00^{-3}	33.33^{-3}	0.06^{-3}	0.33^{-3}	0^{-3}	a^{-3}	0.10^{-3}	1.99^{-3}	0.00^{-3}	50.00^{-3}
–	–	–	–	–	–	–	–	–	–	–	–
0^{-1}	0^{-1}	0^{-1}	a^{-1}	0^{-1}	0^{-1}	0^{-1}	a^{-1}	0.02^{-1}	0^{-1}	0^{-1}	a^{-1}
–	–	–	–	–	–	–	–	–	–	–	–
0.04^{-2}	0^{-2}	a^{-2}	a^{-2}	0.00^{-2}	0^{-2}	a^{-2}	a^{-2}	0.17^{-2}	0.03^{-2}	0.00^{-2}	100.00^{-2}
a	1.87	0.06	40.35	a	2.70	0.05	40.38	a	43.21	0.07	39.44
–	–	–	–	–	–	–	–	–	–	–	–
0.13^{-1}	–	a^{-1}	a^{-1}	0.04^{-1}	–	a^{-1}	a^{-1}	0.06^{-1}	–	a^{-1}	a^{-1}
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	a	a	0.03	–	a	a	0.05	–	a	a
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
8.59	7.05	0.43	26.30	0.68	0.53	0.07	59.15	0.52	4.92	0.22	59.00
3.05^{-1}	8.67^{-1}	0.56^{-1}	30.59^{-1}	0.76^{-1}	1.57^{-1}	0.12^{-1}	46.96^{-1}	12.28^{-1}	10.16^{-1}	0.51^{-1}	59.49^{-1}
0.64^{-1}	8.98^{-1}	0.15^{-1}	32.41^{-1}	0.01^{-1}	1.00^{-1}	0.03^{-1}	40.63^{-1}	0.55^{-1}	3.62^{-1}	0.09^{-1}	50.55^{-1}
1.42^{-1}	4.56^{-1}	0.16^{-1}	34.16^{-1}	0.32^{-1}	1.11^{-1}	0.10^{-1}	36.89^{-1}	1.46^{-1}	1.44^{-1}	0.24^{-1}	53.36^{-1}
0.04^{-1}	0.76^{-1}	0.01^{-1}	37.50^{-1}	0.01^{-1}	0.03^{-1}	0^{-1}	a^{-1}	0.07^{-1}	0.17^{-1}	0^{-1}	a^{-1}
0.44^{-1}	12.21^{-1}	0.55^{-1}	22.57^{-1}	0.08^{-1}	3.70^{-1}	0.18^{-1}	51.37^{-1}	3.02^{-1}	7.21^{-1}	0.20^{-1}	48.04^{-1}
1.93	5.63	0.48	28.84	0.20	0.49	0.21	53.81	0.36	13.09	0.50	60.92
0.39^{-1}	0.94^{-1}	0.03^{-1}	27.27^{-1}	0.01^{-1}	0.25^{-1}	0.01^{-1}	88.89^{-1}	0.97^{-1}	0.38^{-1}	0.01^{-1}	50.00^{-1}
0	10.48	0.45	30.38	0	1.03	0.06	61.82	0	10.41	0.33	66.36
46.05	61.59	1.80	31.81	4.31	4.59	0	a	31.78	81.81	0.38	55.97
–	–	–	–	–	–	–	–	–	–	–	–
5.24^{-1}	5.32^{-1}	0.28^{-1}	27.14^{-1}	1.30^{-1}	1.49^{-1}	0.08^{-1}	41.77^{-1}	3.85^{-1}	3.27^{-1}	0.57^{-1}	50.62^{-1}
0.19^{-1}	7.18^{-1}	0.10^{-1}	22.22^{-1}	0.16^{-1}	1.17^{-1}	0.10^{-1}	58.76^{-1}	1.07^{-1}	4.69^{-1}	0.20^{-1}	51.78^{-1}
2.90^{-1}	4.02^{-1}	0.20^{-1}	23.53^{-1}	0.45^{-1}	0.34^{-1}	0.02^{-1}	46.67^{-1}	2.44^{-1}	7.13^{-1}	0.21^{-1}	54.93^{-1}
0^{-1}	45.82^{-1}	2.04^{-1}	35.46^{-1}	0^{-1}	6.60^{-1}	0.69^{-1}	53.78^{-1}	0^{-1}	59.25^{-1}	1.24^{-1}	100.00^{-1}
0.36	2.16	0.06	32.76	0.03	0.20	0.01	30.00	1.51	2.40	0.03	80.00
a	6.47	0.12	38.84	a	0.68	0.02	61.90	a	4.40	0.05	80.77
0.01	79.00	0.01	22.22	0	0.00	0	a	0.04	–	0	a
0.10^{-1}	0.19^{-1}	0.00^{-1}	0^{-1}	0.01^{-1}	0^{-1}	0^{-1}	a^{-1}	0.01^{-1}	0.66^{-1}	0.00^{-1}	50.00^{-1}
0.08^{-1}	11.50^{-1}	1.02^{-1}	25.71^{-1}	0.02^{-1}	1.53^{-1}	0.21^{-1}	58.69^{-1}	0.22^{-1}	25.54^{-1}	0.73^{-1}	66.62^{-1}
a	65.99	–	–	a	8.16	–	–	0.37	71.17	–	–
a	16.40	0.86	39.09	a	1.37	0.05	59.18	a	15.93	0.39	66.33
0.01^{-2}	37.12^{-2}	2.18^{-2}	38.63^{-2}	a^{-2}	3.99^{-2}	0.30^{-2}	52.96^{-2}	0.14^{-2}	27.37^{-2}	0.77^{-2}	62.84^{-2}
0.02	8.65	0.52	33.40	0	1.18	0.06	53.57	0.22	12.79	0.22	65.02
1.55^{-1}	1.77^{-1}	0.10^{-1}	28.28^{-1}	0.17^{-1}	0.35^{-1}	0.06^{-1}	67.86^{-1}	0.31^{-1}	0.99^{-1}	0.05^{-1}	60.87^{-1}
13.92^{-1}	41.54^{-1}	0.80^{-1}	30.30^{-1}	0.83^{-1}	4.47^{-1}	0.30^{-1}	56.38^{-1}	16.32^{-1}	40.43^{-1}	1.51^{-1}	56.42^{-1}
2.39^{-1}	10.88^{-1}	0.83^{-1}	25.93^{-1}	0.35^{-1}	0.40^{-1}	0.06^{-1}	53.45^{-1}	0.91^{-1}	15.38^{-1}	0.97^{-1}	62.37^{-1}
10.32	57.31	3.59	24.41	2.10	5.00	0.31	54.89	35.96	84.04	4.30	57.03
a	2.24	0.01	20.00	a	0.97	0.02	31.25	a	4.40	0.01	91.67
a	1.75	0.03	14.71	a	0.82	0.01	50.00	a	2.37	0.06	63.33
a	1.21	0.03	36.36	a	0.29	0.01	80.00	a	0.93	0.03	54.84
–	–	–	–	–	–	–	–	–	–	–	–
a	7.31	0.16	37.50	a	1.08	0.06	32.20	a	4.40	0.23	59.05

Table S5: Tertiary graduates in 2008 and 2013 and graduates in science, engineering, agriculture and health in 2013

	2008		2013					
	Tertiary graduates		Tertiary graduates		Science			
	MF (000s)	Females (%)	MF (000s)	Females (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
Other Europe and West Asia								
Armenia	35.00^{+2}	61.5^{+2}	–	–	0^{-3}	2.52^{-3}	0.11^{-3}	22.52^{-3}
Azerbaijan	49.20	53.5	47.04^{-1}	52.1^{-1}	0.19^{-1}	4.27^{-1}	0.10^{-1}	27.00^{-1}
Belarus	112.88	–	137.46	60.8	0	2.43	0.21	50.48
Georgia	17.73^{+2}	60.4^{+2}	17.68	56.8	0.43	1.64	0.06	55.56
Iran, Islamic Rep. of	457.57^{+1}	52.0^{+1}	716.10	45.6	1.19	53.83	0.77	40.08
Israel	–	–	–	–	–	–	–	–
Moldova, Rep. of	27.06	58.4	34.81	59.6	0.48	1.28	0.05	55.56
Russian Federation	2 064.47^{+1}	–	–	–	30.32^{-2}	97.20^{-2}	–	–
Turkey	444.76	46.0	607.98^{-1}	47.1^{-1}	17.01^{-1}	34.19^{-1}	1.16^{-1}	50.73^{-1}
Ukraine	610.23	–	621.79	55.0	7.54	30.83	1.27	50.90
European Free Trade Assoc.								
Iceland	3.63	66.2	4.10^{-1}	64.5^{-1}	0.01^{-1}	0.31^{-1}	0.01^{-1}	35.71^{-1}
Liechtenstein	0.18	30.1	0.31^{-1}	30.2^{-1}	a^{-1}	0^{-1}	0^{-1}	a^{-1}
Norway	35.21	60.6	44.75	58.7	0.11	2.74	0.49	39.84
Switzerland	67.33	48.6	81.91	48.3	0.02	5.56	1.07	35.21
Sub-Saharan Africa								
Angola	–	–	13.55	48.0	–	–	–	–
Benin	14.64^{+1}	31.2^{+1}	16.71^{-2}	29.7^{-2}	–	–	–	–
Botswana	–	–	6.55	–	0.26	0.52	0	–
Burkina Faso	9.48^{+2}	–	16.15	31.8	–	–	–	–
Burundi	2.79^{+2}	28.4^{+2}	7.31^{-1}	30.7^{-1}	0^{-1}	–	0^{-1}	a^{-1}
Cabo Verde	–	–	–	–	–	0.12	0	a
Cameroon	33.99	–	36.31^{-2}	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–	–	–
Chad	–	–	–	–	–	–	–	–
Comoros	–	–	–	–	–	0.09	–	–
Congo	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of	–	–	–	–	–	–	–	–
Côte d'Ivoire	–	–	–	–	–	–	–	–
Djibouti	0.64^{+1}	–	–	–	a^{-2}	–	a^{-2}	a^{-2}
Equatorial Guinea	–	–	–	–	–	–	–	–
Eritrea	3.02^{+2}	–	2.71^{+1}	26.3^{+1}	0.03^{+1}	–	a^{+1}	a^{+1}
Ethiopia	65.37	24.1	–	–	0^{-3}	10.62^{-3}	0.01^{-3}	0^{-3}
Gabon	–	–	–	–	–	–	–	–
Gambia	–	–	–	–	–	–	–	–
Ghana	–	–	79.74	40.7	1.12	6.46	0.01	12.50
Guinea	–	–	–	–	–	1.03	–	–
Guinea–Bissau	–	–	–	–	–	–	–	–
Kenya	–	–	–	–	–	–	–	–
Lesotho	–	–	4.75	65.2	0.04	0.07	0	a
Liberia	3.16^{+2}	30.0^{+2}	4.39^{-1}	38.2^{-1}	–	–	–	–
Madagascar	16.40	47.5	25.26	47.9	0.36	2.24	0.02	34.78
Malawi	–	–	–	–	–	–	–	–
Mali	–	–	–	–	–	–	–	–
Mauritius	–	–	–	–	–	–	–	–
Mozambique	7.05	44.6	10.26	44.9	a	0.21	0	a
Namibia	5.53	58.4	–	–	–	–	–	–
Niger	1.87	–	–	–	–	–	–	–
Nigeria	–	–	–	–	–	–	–	–
Rwanda	–	–	16.05^{-1}	42.7^{-1}	–	–	–	–
Sao Tome and Principe	a	a	–	–	a^{-1}	–	a^{-1}	a^{-1}
Senegal	–	–	–	–	–	–	–	–
Seychelles	a	a	0.08	85.9	0	–	a	a
Sierra Leone	–	–	–	–	–	–	–	–
Somalia	–	–	–	–	–	–	–	–
South Africa	–	–	183.86^{-1}	59.8^{-1}	6.44^{-1}	–	0.57^{-1}	40.53^{-1}
South Sudan	–	–	–	–	–	–	–	–
Swaziland	–	–	2.53	38.8	0	0.28	0.01	37.50
Tanzania	–	–	–	–	–	–	–	–
Togo	–	–	–	–	–	–	–	–
Uganda	–	–	–	–	–	–	–	–
Zambia	–	–	–	–	–	–	–	–
Zimbabwe	30.51^{+2}	45.2^{+2}	13.64	47.6	0.85	0.46	0	a
Arab states								
Algeria	154.84^{+1}	62.5^{+1}	255.44	62.1	–	23.47	–	–
Bahrain	–	–	5.28^{+1}	60.5^{+1}	0.17^{+1}	0.23^{+1}	0.00^{+1}	50.00^{+1}
Egypt	–	–	510.36	52.1	0	20.85	0.60	45.13
Iraq	–	–	–	–	–	–	–	–
Jordan	–	–	60.69^{-2}	48.4^{-2}	0.44^{-2}	2.79^{-2}	0.03^{-2}	52.00^{-2}
Kuwait	–	–	12.72	58.3	a	0.23	a	a
Lebanon	32.30	55.3	54.21	55.8	0^{-2}	3.74^{-2}	0.00^{-2}	100.00^{-2}
Libya	–	–	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–	a	a
Morocco	62.73	32.0	–	–	–	–	–	–

2013											
Engineering, manufacturing and construction				Agriculture				Health and welfare			
Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
0.20^{-3}	2.68^{-3}	0.06^{-3}	10.17^{-3}	0.17^{-3}	1.09^{-3}	0.02^{-3}	43.75^{-3}	3.74^{-3}	0.89^{-3}	0.03^{-3}	17.24^{-3}
0.90^{-1}	2.11^{-1}	0.05^{-1}	13.33^{-1}	0.03^{-1}	0.08^{-1}	0.02^{-1}	31.58^{-1}	2.03^{-1}	1.57^{-1}	0.02^{-1}	39.13^{-1}
17.02	15.98	0.22	37.05	5.98	4.73	0.09	50.00	3.17	3.56	0.18	51.67
0.23	1.03	0.07	40.00	0.08	0.44	0.01	36.36	0.17	2.09	0.03	63.64
102.68	155.87	0.62	17.10	4.77	20.98	0.29	27.59	2.98	18.05	2.31	42.73
–	–	–	–	–	–	–	–	–	–	–	–
2.61	4.50	0.04	45.95	0.14	0.47	0.01	30.77	1.23	–	0.06	43.86
179.08^{-2}	246.39^{-2}	–	–	8.43^{-2}	20.49^{-2}	–	–	64.30^{-2}	48.11^{-2}	–	–
43.18^{-1}	30.96^{-1}	0.63^{-1}	34.39^{-1}	11.39^{-1}	7.82^{-1}	0.25^{-1}	38.15^{-1}	12.85^{-1}	21.43^{-1}	4.61^{-1}	46.33^{-1}
40.49	84.38	1.58	35.47	5.67	14.52	0.41	51.09	22.45	15.27	0.46	59.35
0^{-1}	0.41^{-1}	0.00^{-1}	33.33^{-1}	0.00^{-1}	0.03^{-1}	0^{-1}	a^{-1}	0^{-1}	0.58^{-1}	0.01^{-1}	76.92^{-1}
a^{-1}	0.04^{-1}	0.00^{-1}	0^{-1}	a^{-1}	0^{-1}	0^{-1}	a^{-1}	a^{-1}	0^{-1}	0.01^{-1}	100.00^{-1}
1.71	3.74	0.15	22.88	0.02	0.29	0.02	42.86	0.05	9.04	0.47	58.51
0.04	10.90	0.47	25.75	0	1.32	0.11	81.13	0.27	9.61	0.85	53.72
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
0.26	0.20	0	–	0.03	0.14	0	–	0.57	0.11	0	–
–	–	–	–	–	–	–	–	–	–	–	–
0^{-1}	–	0^{-1}	a^{-1}	0^{-1}	–	0^{-1}	a^{-1}	0^{-1}	–	0.15^{-1}	20.95^{-1}
–	–	0	a	–	–	0	a	–	–	0	a
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
a^{-2}	0^{-2}	a^{-2}	a^{-2}	a^{-2}	0^{-2}	a^{-2}	a^{-2}	a^{-2}	0^{-2}	a^{-2}	a^{-2}
–	–	–	–	–	–	–	–	–	–	–	–
0.51^{+1}	–	a^{+1}	a^{+1}	0.07^{+1}	–	a^{+1}	a^{+1}	0.11^{+1}	–	a^{+1}	a^{+1}
0^{-3}	5.01^{-3}	0^{-3}	a^{-3}	0^{-3}	7.87^{-3}	0.01^{-3}	0^{-3}	0^{-3}	5.40^{-3}	0.10^{-3}	17.71^{-3}
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
2.47	3.09	0.00	0	0.91	1.59	0.02	25.00	1.55	2.68	0.01	16.67
–	2.18	–	–	–	0.90	–	–	–	2.89	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
0.13	–	0	a	0.10	0.05	0	a	0.51	0.10	0	a
–	–	–	–	–	–	–	–	–	–	–	–
0.40	2.08	0.02	0	0.01	0.29	0.00	50.00	0.27	0.61	0.24	57.87
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
a	0.38	0.01	0	a	0.47	0	a	a	0.56	0	a
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
a^{-1}	–	a^{-1}	a^{-1}	a^{-1}	–	a^{-1}	a^{-1}	a^{-1}	–	a^{-1}	a^{-1}
–	–	–	–	–	–	–	–	–	–	–	–
0	–	a	a	0	–	a	a	0	–	a	a
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
5.73^{-1}	–	0.15^{-1}	17.57^{-1}	1.37^{-1}	–	0.09^{-1}	39.78^{-1}	2.07^{-1}	–	0.17^{-1}	62.72^{-1}
–	–	–	–	–	–	–	–	–	–	–	–
0	0.13	0	a	0	0.15	0.01	42.86	0	0.33	0	a
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–
2.70	0.00	0	a	0.02	0.26	0	a	0.18	–	0	a
–	30.68	–	–	–	3.65	–	–	–	5.96	–	–
0.21^{+1}	0.42^{+1}	0^{+1}	a^{+1}	0^{+1}	0.00^{+1}	0^{+1}	a^{+1}	0.04^{+1}	0.27^{+1}	0^{+1}	a^{+1}
0	38.42	0.31	27.01	0	10.86	0.72	42.82	0	65.58	1.29	50.54
–	–	–	–	–	–	–	–	–	–	–	–
0.20^{-2}	1.95^{-2}	0.00^{-2}	0^{-2}	0.01^{-2}	1.80^{-2}	0.01^{-2}	37.50^{-2}	0^{-2}	1.00^{-2}	0^{-2}	a^{-2}
2.41	0.77	a	a	a	–	a	a	0.66	0.39	a	a
0.88^{-2}	3.31^{-2}	0.00^{-2}	25.00^{-2}	0^{-2}	0.17^{-2}	0^{-2}	a^{-2}	0.97^{-2}	2.84^{-2}	0^{-2}	a^{-2}
–	–	–	–	–	–	–	–	–	–	–	–
–	–	a	a	–	–	a	a	–	–	a	a
–	–	–	–	–	–	–	–	–	–	–	–

Table S5: Tertiary graduates in 2008 and 2013 and graduates in science, engineering, agriculture and health in 2013

	2008		2013					
	Tertiary graduates		Tertiary graduates		Science			
	MF (000s)	Females (%)	MF (000s)	Females (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
Oman	11.54^{+1}	58.7^{+1}	16.68	56.1	0.53	1.56	0.00	100.00
Palestine	25.28	57.7	35.28	59.5	0.48	2.35	0	a
Qatar	1.79	66.7	2.28	60.8	0.04	0.08	a	a
Saudi Arabia	112.13	57.4	141.20	51.1	6.52	19.13	0.03	32.00
Sudan	–	–	124.49	51.2	3.46	8.76	0.13	31.25
Syrian Arab Rep.	51.32	51.5	58.69	56.2	–	–	–	–
Tunisia	–	–	65.42	65.9	a	16.92	0.31	60.33
United Arab Emirates	14.32	60.8	25.68	55.6	0.59	1.50	0	a
Yemen	–	–	–	–	–	–	–	–
Central Asia								
Kazakhstan	–	–	238.22	56.3	0.63	4.38	0.07	60.27
Kyrgyzstan	35.58	60.8	50.23	60.1	0.15	1.63	0.11	56.36
Mongolia	29.60	65.6	37.75	64.5	0.02	2.00	0.01	55.56
Tajikistan	–	–	46.80	37.9	0.28	–	0.07	–
Turkmenistan	–	–	–	–	0^{+1}	0.39^{+1}	–	–
Uzbekistan	73.73	38.7	77.22^{-2}	44.3^{-2}	a^{-2}	5.71^{-2}	0.15^{-2}	29.61^{-2}
South Asia								
Afghanistan	9.27	16.7	–	–	–	–	–	–
Bangladesh	184.91	–	316.02^{-1}	41.8^{-1}	0^{-1}	35.02^{-1}	0.13^{-1}	43.75^{-1}
Bhutan	–	–	1.63	34.2	0	–	a	a
India	–	–	–	–	–	–	–	–
Maldives	–	–	–	–	–	–	–	–
Nepal	44.46	–	61.52	48.3	a	2.36	0.00	25.00
Pakistan	–	–	–	–	–	–	–	–
Sri Lanka	27.91^{+2}	58.5^{+2}	34.92	57.6	0.24^{-1}	2.66^{-1}	0.05^{-1}	54.17^{-1}
South–East Asia								
Brunei Darussalam	1.54	66.5	1.91	64.1	0.09	0.10	0	a
Cambodia	16.71	27.5	–	–	–	–	–	–
China	7 071.05	47.9	9 366.20	50.7	–	–	–	–
China, Hong Kong SAR	–	–	–	–	–	–	–	–
China, Macao SAR	6.79	48.6	6.07	59.9	0.00	0.20	0.02	21.05
Indonesia	799.37^{+1}	–	–	–	13.41^{-4}	30.81^{-4}	–	–
Japan	1 033.77	48.5	980.90^{-1}	48.3^{-1}	0^{-1}	28.07^{-1}	2.42^{-1}	23.65^{-1}
Korea, DPR	–	–	–	–	–	–	–	–
Korea, Rep. of	605.28	49.0	618.28	50.5	5.21	37.36	1.63	29.53
Lao PDR	18.99^{+1}	42.3^{+1}	37.38	45.4	0.78	0.68	0	a
Malaysia	206.59	58.6	261.82^{-1}	56.6^{-1}	12.98^{-1}	11.44^{-1}	0.55^{-1}	40.44^{-1}
Myanmar	–	–	295.94^{-1}	64.6^{-1}	5.13^{-1}	122.78^{-1}	0.20^{-1}	89.00^{-1}
Philippines	481.33^{+2}	56.0^{+2}	564.77	56.8	18.83	63.86	0.21	62.15
Singapore	–	–	–	–	–	–	–	–
Thailand	541.89	55.0	–	–	–	–	–	–
Timor–Leste	–	–	–	–	–	–	–	–
Viet Nam	243.52	43.1	406.07	43.0	0	0.00	0	a
Oceania								
Australia	306.90	55.9	386.63^{-2}	57.3^{-2}	4.65^{-2}	26.36^{-2}	1.74^{-2}	44.83^{-2}
New Zealand	54.45	60.9	71.93^{-1}	59.4^{-1}	2.80^{-1}	6.36^{-1}	0.36^{-1}	47.21^{-1}
Cook Islands	a	a	–	–	–	–	–	–
Fiji	–	–	–	–	–	–	–	–
Kiribati	a	a	a^{-1}	a^{-1}	a^{-1}	0^{-1}	a^{-1}	a^{-1}
Marshall Islands	–	–	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–	–	–
Nauru	a	a	–	–	–	–	–	–
Niue	a	a	–	–	–	–	–	–
Palau	–	–	0.09	57.4	a	0.00	a	a
Papua New Guinea	–	–	–	–	–	–	–	–
Samoa	–	–	–	–	–	–	–	–
Solomon Islands	a	a	–	–	–	–	–	–
Tonga	–	–	–	–	–	–	–	–
Tuvalu	a	a	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–	–	–

Source: UNESCO Institute for Statistics (UIS)

N.B.: See Key To All Tables at the end of Table S10.

	2013											
	Engineering, manufacturing and construction				Agriculture				Health and welfare			
	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)	Post–secondary diploma MF (000s)	Bachelor's and master's degrees MF (000s)	PhDs MF (000s)	Female PhDs (%)
	0.64	2.52	0.00	0	0.45	0.05	0.00	0	2.42	0.47	0	a
	0.48	2.09	0	a	0	0.17	0	a	1.30	1.77	0	a
	0.27	0.29	a	a	a	–	a	a	0.03	0.22	a	a
	7.87	5.30	0.02	5.88	0.02	0.43	0.00	0	2.45	7.38	0.14	25.17
	2.91	4.96	0.03	21.43	0.02	3.00	0.03	34.48	0.97	13.75	0.06	37.70
	–	–	–	–	–	–	–	–	–	–	–	–
	a	11.02	0.12	49.18	a	0.90	0.01	50.00	a	5.81	0	a
	0.22	3.52	0	a	0	–	0	a	0.07	1.71	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	14.66	31.80	0.04	37.84	3.55	–	0.01	18.18	4.18	–	0	a
	1.05	6.17	0.08	40.74	0.15	–	0.01	10.00	1.94	–	0.05	66.00
	0.07	4.22	0.01	36.36	0.01	0.81	0.01	91.67	0.62	2.34	0.02	78.95
	0.97	–	0.02	–	0.23	–	0.03	–	5.90	–	0.02	–
	1.16^{+1}	0.93^{+1}	–	–	0.30^{+1}	0.13^{+1}	–	–	0.30^{+1}	0.30^{+1}	–	–
	a^{-2}	10.34^{-2}	0.12^{-2}	22.88^{-2}	a^{-2}	2.70^{-2}	0.06^{-2}	29.31^{-2}	a^{-2}	3.53^{-2}	0.13^{-2}	55.30^{-2}
	–	–	–	–	–	–	–	–	–	–	–	–
	0^{-1}	14.12^{-1}	0.09^{-1}	14.94^{-1}	0^{-1}	3.87^{-1}	0.07^{-1}	43.24^{-1}	0^{-1}	5.00^{-1}	0.27^{-1}	39.26^{-1}
	0.17	–	a	a	0.07	–	a	a	0.06	–	a	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	a	0.14	0.00	0	a	–	0	a	a	1.30	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	0.48^{-1}	1.07^{-1}	0.01^{-1}	60.00^{-1}	0.34^{-1}	0.75^{-1}	0.03^{-1}	64.52^{-1}	0.26^{-1}	1.19^{-1}	0.23^{-1}	44.21^{-1}
	0.18	0.04	0	a	0	–	0	a	0.04	0.04	0	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	0	0.11	0.00	33.33	0	0.00	0	a	0.01	0.36	0.01	14.29
	41.29^{-4}	87.82^{-4}	–	–	14.39^{-4}	33.06^{-4}	–	–	13.94^{-4}	32.05^{-4}	–	–
	41.67^{-1}	122.98^{-1}	3.56^{-1}	14.35^{-1}	3.04^{-1}	21.83^{-1}	1.00^{-1}	31.27^{-1}	69.74^{-1}	52.26^{-1}	5.26^{-1}	31.23^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	54.09	90.63	3.14	14.37	1.78	5.36	0.32	25.55	46.58	39.77	2.52	46.79
	1.59	–	0	a	1.25	–	0	a	0.47	–	0	a
	32.23^{-1}	23.09^{-1}	0.63^{-1}	26.34^{-1}	2.42^{-1}	2.43^{-1}	0.07^{-1}	32.86^{-1}	12.23^{-1}	18.02^{-1}	0.20^{-1}	46.80^{-1}
	5.73^{-1}	5.61^{-1}	0.06^{-1}	72.41^{-1}	0^{-1}	1.54^{-1}	0^{-1}	a^{-1}	2.14^{-1}	1.71^{-1}	0.06^{-1}	83.33^{-1}
	15.24	47.10	0.06	48.28	4.07	9.65	0.07	55.41	4.39	53.11	0.16	69.14
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	61.27	36.72	0.09	13.98	8.17	13.27	0.01	0	7.46	7.33	0.01	41.67
	8.10^{-2}	21.07^{-2}	0.88^{-2}	25.51^{-2}	1.96^{-2}	1.79^{-2}	0.28^{-2}	49.64^{-2}	19.15^{-2}	45.82^{-2}	0.99^{-2}	63.44^{-2}
	1.41^{-1}	3.60^{-1}	0.13^{-1}	29.77^{-1}	0.57^{-1}	0.38^{-1}	0.02^{-1}	73.33^{-1}	2.01^{-1}	9.19^{-1}	0.15^{-1}	58.39^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	a^{-1}	0^{-1}	a^{-1}	a^{-1}	a^{-1}	0^{-1}	a^{-1}	a^{-1}	a^{-1}	0^{-1}	a^{-1}	a^{-1}
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	a	0.01	a	a	a	0.01	a	a	a	0.01	a	a
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–

Table S6: Total researchers and researchers per million inhabitants, 2009 and 2013

	Researchers in full–time equivalents					
	2009			2013		
	Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants
North America						
Canada	150 220	–	4 451	156 550[-1]	–	4 494[-1]
United States of America	1 250 984[r]	–	4 042[r]	1 265 064[-1,r]	–	3 984[-1,r]
Latin America						
Argentina	43 717	50.52	1 092	51 598[-1]	51.61[-1]	1 256[-1]
Belize	–	–	–	–	–	–
Bolivia	1 422	–	142	1 646[-3]	–	162[-3]
Brazil	129 102	–	667	138 653[-3]	–	710[-3]
Chile	4 859[q]	31.41[q]	286[q]	6 798[-1,q]	31.66[-1,q]	389[-1,q]
Colombia	7 500	36.54	164	7 702[-1]	37.15[-1]	161[-1]
Costa Rica	4 479[b]	51.33[-1]	973[b]	6 107[-2,b]	45.04[-2,h]	1 289[-2,b]
Ecuador	1 739	39.81	118	2 736[-2]	39.30[-2]	179[-2]
El Salvador	–	–	–	–	–	–
Guatemala	554[q]	35.20[q]	40[q]	411[-1,q]	41.85[-1,q]	27[-1,q]
Guyana	–	–	–	–	–	–
Honduras	–	–	–	–	–	–
Mexico	42 973	–	369	46 125[-2]	–	386[-2]
Nicaragua	–	–	–	–	–	–
Panama	394	–	109	438[-2]	30.59[-2]	117[-2]
Paraguay	466[-1]	–	75[-1]	1 081[-1]	–	162[-1]
Peru	–	–	–	–	–	–
Suriname	–	–	–	–	–	–
Uruguay	1 617	–	481	1 803	47.48	529
Venezuela	5 209[q]	53.41[q]	182[q]	8 686[-1,q]	–	290[-1,q]
Caribbean						
Antigua and Barbuda	–	–	–	–	–	–
Bahamas	–	–	–	–	–	–
Barbados	–	–	–	–	–	–
Cuba	–	–	–	–	–	–
Dominica	–	–	–	–	–	–
Dominican Rep.	–	–	–	–	–	–
Grenada	–	–	–	–	–	–
Haiti	–	–	–	–	–	–
Jamaica	–	–	–	–	–	–
St Kitts and Nevis	–	–	–	–	–	–
St Lucia	–	–	–	–	–	–
St Vincent and the Grenadines	–	–	–	–	–	–
Trinidad and Tobago	–	–	–	–	–	–
European Union						
Austria	34 664	22.40	4 141	39 923[r,v]	22.80[-2]	4 699[r,v]
Belgium	38 225	31.56	3 519	44 649[v]	31.73[-2]	4 021[v]
Bulgaria	11 968	48.43	1 607	12 275	49.61[-1]	1 699
Croatia	6 931	48.82	1 593	6 529	49.82[-1]	1 522
Cyprus	873	37.57	801	885[v]	37.51[-1]	776[v]
Czech Rep.	28 759	26.04	2 743	34 271	24.72[-1]	3 202
Denmark	36 789	29.77	6 659	40 858[r,v]	31.59[-2]	7 271[r,v]
Estonia	4 314	41.63	3 311	4 407	42.84[-1]	3 424
Finland	40 849	–	7 644	39 196[s]	–	7 223[s]
France	234 366[p]	–	3 727[p]	265 177[s,v]	26.05[-1,q]	4 125[s,v]
Germany	317 307	20.57	3 815	360 310[r,v]	22.08[-2]	4 355[r,v]
Greece	21 014[-2,r]	31.71[-4]	1 899[-2,r]	29 055[s]	38.92[-2,s]	2 611[s]
Hungary	20 064	30.42	2 000	25 038	28.41[-1]	2 515
Ireland	14 189[r]	32.79[r]	3 217[r]	15 732[-1,r]	30.27[-2,r]	3 438[-1,r]
Italy	101 840	34.19	1 691	117 973[v]	35.75[-1]	1 934[v]
Latvia	3 621	50.35	1 714	3 625	50.85[-1]	1 768
Lithuania	8 490	50.45	2 737	8 557	50.18[-1]	2 836
Luxembourg	2 396	22.30	4 811	2 615[s,v]	24.18[-2]	4 931[s,v]
Malta	494	29.15	1 168	878[v]	28.18[-1]	2 047[v]
Netherlands	46 958	–	2 835	72 325[s,v]	26.56[-1]	4 316[s,v]
Poland	61 105	38.15	1 600	71 472	36.73[-1]	1 870
Portugal	39 834	44.66	3 765	43 321[v]	44.49[-1]	4 084[v]
Romania	19 271	44.85	879	18 704[s]	44.78[-1,s]	862[s]
Slovakia	13 290	42.19	2 450	14 727	41.79	2 702
Slovenia	7 446	33.75	3 642	8 707[s]	33.99[-1,s]	4 202[s]
Spain	133 803	38.51	2 924	123 225	38.47[-1]	2 626
Sweden	47 160[q]	29.70[q]	5 065[q]	62 294[q,s]	30.19[-2,q,s]	6 509[q,s]
United Kingdom	256 124[r]	–	4 151[r]	259 347[r,v]	–	4 108[r,v]
South–East Europe						
Albania	467[-1,q]	44.33[-1,q]	148[-1,q]	–	–	–
Bosnia and Herzegovina	745[-2,q]	–	193[-2,q]	829[s]	36.50	216[s]
Macedonia, FYR	893	53.86	425	1 402	51.04	665
Montenegro	–	–	–	404	48.68[-2,r]	650
Serbia	10 444	47.72	1 076	12 342	50.00[-1]	1 298

Researchers in head counts						
2009			2013			
Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants	
						North America
–	–	–	–	–	–	Canada
–	–	–	–	–	–	United States of America
						Latin America
67 245	51.91	1 680	81 748[-1]	52.66[-1]	1 990[-1]	Argentina
–	–	–	–	–	–	Belize
1 947	63.23	195	2 153[-3]	62.75[-3]	212[-3]	Bolivia
216 672	–	1 120	234 797[-3]	–	1 203[-3]	Brazil
8 770[q]	32.30[q]	516[q]	10 447[-1,q]	30.97[-1,q]	598[-1,q]	Chile
16 201	37.19	354	16 127[-1]	37.75[-1]	338[-1]	Colombia
7 223[b]	43.26[h]	1 570[b]	8 848[-2,b]	42.65[-2,h]	1 868[-2,b]	Costa Rica
2 413	38.96	164	4 027[-2]	37.37[-2]	264[-2]	Ecuador
455	35.16	74	662	38.82	104	El Salvador
756[q]	35.19[q]	54[q]	666[-1,q]	44.74[-1,q]	44[-1,q]	Guatemala
–	–	–	–	–	–	Guyana
539[-6]	26.53[-6]	81[-6]	–	–	–	Honduras
42 973	31.57[-6,r]	369	46 125[-2]	–	386[-2]	Mexico
326[-5]	42.48[-7,q]	61[-5]	–	–	–	Nicaragua
482	41.12[-5]	133	552[-2,s]	–	148[-2,s]	Panama
850[-1]	51.76[-1]	136[-1]	1 704[-1]	51.68[-1]	255[-1]	Paraguay
4 965[-5]	–	181[-5]	–	–	–	Peru
–	–	–	–	–	–	Suriname
2 596	51.58	773	2 403	49.11	705	Uruguay
6 829[q]	54.52[q]	239[q]	10 256[-1,q]	56.29[-1,q]	342[-1,q]	Venezuela
						Caribbean
–	–	–	–	–	–	Antigua and Barbuda
–	–	–	–	–	–	Bahamas
–	–	–	–	–	–	Barbados
5 448	46.64	483	4 477	46.59	397	Cuba
–	–	–	–	–	–	Dominica
–	–	–	–	–	–	Dominican Rep.
–	–	–	–	–	–	Grenada
–	–	–	–	–	–	Haiti
–	–	–	–	–	–	Jamaica
–	–	–	–	–	–	St Kitts and Nevis
–	–	–	–	–	–	St Lucia
21[-7]	–	194[-7]	–	–	–	St Vincent and the Grenadines
787	52.86	595	914[-1]	43.76[-1]	683[-1]	Trinidad and Tobago
						European Union
59 341	28.44	7 088	65 609[-2]	28.99[-2]	7 780[-2]	Austria
55 858	32.71	5 142	63 207[-2]	33.47[-2]	5 743[-2]	Belgium
14 699	47.62	1 974	15 219[-1]	48.61[-1]	2 091[-1]	Bulgaria
12 108	46.42	2 783	11 402[-1]	47.71[-1]	2 647[-1]	Croatia
1 696	35.55	1 555	1 914[-1]	37.30[-1]	1 695[-1]	Cyprus
43 092	28.86	4 109	47 651[-1]	27.50[-1]	4 470[-1]	Czech Rep.
54 049	31.75	9 784	58 568[-1]	34.78[-1,r]	10 463[-1]	Denmark
7 453	42.48	5 720	7 634[-1]	43.99[-1]	5 914[-1]	Estonia
55 797	31.42	10 441	56 704[-1]	32.25[-1]	10 484[-1]	Finland
296 093	26.92[p]	4 708	356 469[-1,s]	25.59[-1,q,s]	5 575[-1,s]	France
487 242	24.96	5 857	522 010[-2]	26.80[-2]	6 297[-2]	Germany
33 396[-4]	36.37[-4]	3 025[-4]	45 239[-2,s]	36.71[-2,s]	4 069[-2,s]	Greece
35 267	32.11	3 516	37 019[-1]	30.94[-1]	3 711[-1]	Hungary
20 901[r]	34.23[r]	4 739[r]	22 131[-2]	32.43[-2]	4 893[-2]	Ireland
149 314	33.84	2 479	157 960[-1]	35.50[-1]	2 594[-1]	Italy
6 324	52.37	2 994	7 995[-1]	52.81[-1]	3 880[-1]	Latvia
13 882	51.01	4 475	17 677[-1]	52.36[-1]	5 839[-1]	Lithuania
2 951	21.21	5 924	3 267[-2]	24.00[-2]	6 327[-2]	Luxembourg
945	29.42	2 235	1 451[-1]	29.50[-1]	3 392[-1]	Malta
54 505	25.88	3 291	104 265[-1,s]	26.31[-1,s]	6 238[-1,s]	Netherlands
98 165	39.52	2 570	103 627[-1]	38.29[-1]	2 712[-1]	Poland
75 206	44.33	7 108	81 750[-1]	45.02[-1]	7 709[-1]	Portugal
30 645	44.73	1 398	27 838[-1,s]	45.14[-1,s]	1 280[-1,s]	Romania
21 832	42.47	4 024	24 441	42.70	4 484	Slovakia
10 444	35.66	5 109	12 362[-1,s]	35.80[-1,s]	5 979[-1,s]	Slovenia
221 314	38.11	4 837	215 544[-1]	38.81[-1]	4 610[-1]	Spain
72 864	35.68	7 826	80 039[-2]	37.22[-2]	8 471[-2]	Sweden
385 489[r]	37.93[r]	6 248[r]	442 385[-1,r]	37.83[-1,r]	7 046[-1,r]	United Kingdom
						South-East Europe
1 721[-1,q]	44.33[-1,q]	545[-1,q]	–	–	–	Albania
2 953[-2,q]	–	763[-2,q]	1 245[s]	38.88	325[s]	Bosnia and Herzegovina
1 795	51.25	855	2 867	49.15	1 361	Macedonia, FYR
671[-2]	41.28[-2]	1 086[-2]	1 546[-2,s]	49.87[-2]	2 491[-2,s]	Montenegro
12 006	47.44	1 237	13 249[-1]	49.64[-1]	1 387[-1]	Serbia

Table S6: Total researchers and researchers per million inhabitants, 2009 and 2013

	Researchers in full–time equivalents					
	2009			2013		
	Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants
Other Europe and West Asia						
Armenia	–	–	–	–	–	–
Azerbaijan	–	–	–	–	–	–
Belarus	–	–	–	–	–	–
Georgia	–	–	–	–	–	–
Iran, Islamic Rep. of	52 256[i]	24.21[i]	711[i]	54 813[-3,i]	26.96[-3,i]	736[-3,i]
Israel	–	–	–	63 728[-1,p,r]	21.19[-2,p]	8 337[-1,p,r]
Moldova, Rep. of	2 861	48.03	794	2 623	47.85	752
Russian Federation	442 263	–	3 078	440 581	–	3 085
Turkey	57 759	33.37	811	89 075	32.96	1 189
Ukraine	61 858[q]	43.89[-2]	1 337[q]	52 626[q]	–	1 163[q]
European Free Trade Assoc.						
Iceland	2 505	39.93	7 983	2 258[-2,s]	35.96[-2,s]	7 012[-2,s]
Liechtenstein	–	–	–	–	–	–
Norway	26 273	–	5 433	28 343	–	5 621
Switzerland	25 142[-1]	–	3 285[-1]	35 950[-1]	–	4 495[-1]
Sub–Saharan Africa						
Angola	–	–	–	1 150[-2]	27.83[-2]	57[-2]
Benin	–	–	–	–	–	–
Botswana	–	–	–	352[-1]	26.64[-1]	176[-1]
Burkina Faso	–	–	–	742[-3]	21.61[-3]	48[-3]
Burundi	–	–	–	–	–	–
Cabo Verde	60[-7,q]	–	131[-7,q]	25[-2,l,q,s]	36.00[-2,l,q]	51[-2,l,q,s]
Cameroon	–	–	–	–	–	–
Central African Rep.	–	–	–	–	–	–
Chad	–	–	–	–	–	–
Comoros	–	–	–	–	–	–
Congo	102[-9,q]	12.78[-9]	33[-9,q]	–	–	–
Congo, Dem. Rep. of	–	–	–	–	–	–
Côte d'Ivoire	1 269[-4,q]	16.55[-4,q]	73[-4,q]	–	–	–
Djibouti	–	–	–	–	–	–
Equatorial Guinea	–	–	–	–	–	–
Eritrea	–	–	–	–	–	–
Ethiopia	1 615[-2]	7.74[-2]	20[-2]	4 267[s]	13.04	45[s]
Gabon	–	–	–	–	–	–
Gambia	179	20.00[-1]	110	59[-2,q,s]	20.48[-2]	34[-2,q,s]
Ghana	392[-2]	17.59[-2]	17[-2]	941[-3,s]	17.30[-3]	39[-3,s]
Guinea	–	–	–	–	–	–
Guinea–Bissau	–	–	–	–	–	–
Kenya	2 105[-2,q]	17.84[-2,r]	56[-2,q]	9 305[-3,s]	20.00[-3]	227[-3,s]
Lesotho	46[q]	41.03[q]	23[q]	12[-2,l,q]	32.77[-2,q]	6[-2,l,q]
Liberia	–	–	–	–	–	–
Madagascar	930[q]	31.72	45[q]	1 106[-2,q,s]	34.18[-2]	51[-2,q,s]
Malawi	406[-2]	21.86[-2]	30[-2]	732[-3,h]	18.55[-3]	49[-3,h]
Mali	513[-3,q]	13.26[-3,q]	42[-3,q]	443[-3]	14.06[-3]	32[-3]
Mauritius	–	–	–	228[-1,h]	41.44[-1,h]	184[-1,h]
Mozambique	273[h,i,q]	33.72[q]	12[h,i,q]	912[-3,h,s]	32.24[-3]	38[-3,h,s]
Namibia	–	–	–	–	–	–
Niger	101[-4,q]	–	8[-4,q]	–	–	–
Nigeria	5 677[-2,h,q]	23.35[-2,q]	39[-2,h,q]	–	–	–
Rwanda	123[l,q]	34.17[l]	12[l,q]	–	–	–
Sao Tome and Principe	–	–	–	–	–	–
Senegal	4 527[-1]	23.81[-1]	370[-1]	4 679[-3]	24.83[-3]	361[-3]
Seychelles	13[-4,q]	30.77[-4,q]	149[-4,q]	–	–	–
Sierra Leone	–	–	–	–	–	–
Somalia	–	–	–	–	–	–
South Africa	19 793	39.02	389	21 383[-1]	43.42[-1]	408[-1]
South Sudan	–	–	–	–	–	–
Swaziland	–	–	–	–	–	–
Tanzania	–	–	–	1 600[-3,h,q]	24.59[-3]	36[-3,h,q]
Togo	216[-2,h]	12.21[-2,q]	37[-2,h]	242[-1,h,s]	9.45[-1]	36[-1,h,s]
Uganda	–	–	–	1 263[-3]	26.26[-3]	37[-3]
Zambia	536[-1]	34.33[-1]	43[-1]	–	–	–
Zimbabwe	–	–	–	1 305[-1,h]	25.45[-1]	95[-1,h]
Arab states						
Algeria	5 593[-4,q]	36.53[-4,q]	165[-4,q]	–	–	–
Bahrain	39[l,q]	41.03[l,q]	33[l,q]	67[l,q]	50.75[l,q]	50[l,q]
Egypt	35 158[q]	36.00	458[q]	47 652[h]	43.69[h]	581[h]
Iraq	12 048[b,h]	34.06[h]	399[b,h]	13 559[-2,b,h]	33.94[-2,h]	426[-2,b,h]
Jordan	–	–	–	–	–	–
Kuwait	402[k,q]	37.06[k,q]	141[k,q]	439[-1,k,q]	36.22[-1,k,q]	135[-1,k,q]
Lebanon	–	–	–	–	–	–

Researchers in head counts						
2009			2013			
Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants	
						Other Europe and West Asia
5 542[q]	45.69[q]	1 867[q]	3 870[q]	48.14[q]	1 300[q]	Armenia
11 041	52.35	1 229	15 784	53.34	1 677	Azerbaijan
20 543	42.72	2 157	18 353	41.06	1 961	Belarus
8 112[-4]	52.70[-4]	1 813[-4]	–	–	–	Georgia
101 144[i]	23.69[i]	1 375[i]	115 762[-3,i]	25.86[-3,i]	1 555[-3,i]	Iran, Islamic Rep. of
–	–	–	–	–	–	Israel
3 561	47.32	988	3 250	47.97	932	Moldova, Rep. of
369 237[q]	41.90[q]	2 570[q]	369 015[q]	40.88[q]	2 584[q]	Russian Federation
114 436	36.29	1 606	166 097	36.23	2 217	Turkey
76 147	44.82	1 646	65 641	45.82	1 451	Ukraine
						European Free Trade Assoc.
3 754	42.59	11 963	3 270[-2,s]	37.34[-2,s]	10 154[-2,s]	Iceland
–	–	–	–	–	–	Liechtenstein
44 762	35.23	9 257	46 747[-1]	36.20[-1]	9 361[-1]	Norway
45 874[-1]	30.18[-1]	5 994[-1]	60 278[-1]	32.41[-1]	7 537[-1]	Switzerland
						Sub-Saharan Africa
–	–	–	1 482[-2]	27.06[-2]	73[-2]	Angola
1 000[-2,q,r]	–	115[-2,q,r]	–	–	–	Benin
1 732[-4,q]	30.77[-4,q]	923[-4,q]	690[-1,s]	27.25[-1,s]	344[-1,s]	Botswana
187[-2,q]	13.37[-2]	13[-2,q]	1 144[-3,s]	23.08[-3,s]	74[-3,s]	Burkina Faso
362[q]	13.81	41[q]	379[-2,q]	14.51[-2]	40[-2,q]	Burundi
107[-7,q]	52.34[-7]	233[-7,q]	128[-2,l,q,s]	39.84[-2,l,q]	261[-2,l,q,s]	Cabo Verde
4 562[-1]	21.79[-1]	233[-1]	–	–	–	Cameroon
134[q]	41.46[-2,l]	31[q]	–	–	–	Central African Rep.
–	–	–	–	–	–	Chad
–	–	–	–	–	–	Comoros
–	–	–	–	–	–	Congo
12 470[b]	–	206[b]	–	–	–	Congo, Dem. Rep. of
2 397[-4,q]	16.48[-4,q]	138[-4,q]	–	–	–	Côte d'Ivoire
–	–	–	–	–	–	Djibouti
–	–	–	–	–	–	Equatorial Guinea
–	–	–	–	–	–	Eritrea
2 377[-2]	7.40[-2]	30[-2]	8 221[s]	13.30	87[s]	Ethiopia
531[q]	22.39[q]	350[q]	–	–	–	Gabon
179	20.00[-1]	110	60[-2,q,s]	20.00[-2]	35[-2,q,s]	Gambia
636[-2]	17.92[-2]	28[-2]	2 542[-3,s]	18.29[-3]	105[-3,s]	Ghana
2 117[-9,q]	5.76[-9,q]	242[-9,q]	–	–	–	Guinea
–	–	–	–	–	–	Guinea–Bissau
3 509[-2,q]	17.84[-2]	93[-2,q]	13 012[-3,s]	25.65[-3]	318[-3,s]	Kenya
229[q]	41.03[q]	115[q]	42[-2,l,q]	30.95[-2,q]	21[-2,l,q]	Lesotho
–	–	–	–	–	–	Liberia
1 817[q]	33.90	89[q]	2 364[-2,q,s]	35.36[-2]	109[-2,q,s]	Madagascar
733[-2]	23.19[-2]	53[-2]	1 843[-3,h]	19.53[-3]	123[-3,h]	Malawi
877[-2,i,q]	10.60[-2,q]	69[-2,i,q]	898[-3]	16.04[-3]	64[-3]	Mali
–	–	–	353[-1,h]	41.93[-1,h]	285[-1,h]	Mauritius
771[h,i,q]	33.72[q]	33[h,i,q]	1 588[-3,h,s]	32.24[-3]	66[-3,h,s]	Mozambique
–	–	–	748[-3]	43.72[-3]	343[-3]	Namibia
129[-4,q]	–	10[-4,q]	–	–	–	Niger
17 624[-2,h,q]	23.30[-2,q]	120[-2,h,q]	–	–	–	Nigeria
564[l,q]	21.81[l]	54[l,q]	–	–	–	Rwanda
–	–	–	–	–	–	Sao Tome and Principe
7 859[-1]	24.05[-1]	642[-1]	8 170[-3]	24.86[-3]	631[-3]	Senegal
14[-4,q]	35.71[-4,q]	161[-4,q]	–	–	–	Seychelles
–	–	–	–	–	–	Sierra Leone
–	–	–	–	–	–	Somalia
40 797	40.76	802	42 828[-1]	43.72[-1]	818[-1]	South Africa
–	–	–	–	–	–	South Sudan
–	–	–	–	–	–	Swaziland
2 755[-2,h,q]	20.25[-2]	67[-2,h,q]	3 102[-3,h,q]	25.44[-3]	69[-3,h,q]	Tanzania
834[-2,h]	12.02[-2,q]	143[-2,h]	639[-1,h,s]	10.17[-1]	96[-1,h,s]	Togo
1 703	40.40	52	2 823[-3,s]	24.34[-3]	83[-3,s]	Uganda
612[-1]	30.72[-1]	49[-1]	–	–	–	Zambia
–	–	–	2 739[-1,h]	25.26[-1]	200[-1,h]	Zimbabwe
						Arab states
13 805[-4,q]	34.83[-4,q]	406[-4,q]	–	–	–	Algeria
397[l,q]	33.75[l,q]	333[l,q]	510[l,q]	41.18[l,q]	383[l,q]	Bahrain
89 114[q]	37.34	1 161[q]	110 772[h]	42.77[h]	1 350[h]	Egypt
36 470[b,h]	34.16[h]	1 209[b,h]	40 521[-2,b,h]	34.17[-2,h]	1 273[-2,b,h]	Iraq
11 310[-1,q]	22.54[-1]	1 913[-1,q]	–	–	–	Jordan
402[k,q]	37.06[k,q]	141[k,q]	4 025[h,s]	37.34[h,s]	1 195[h,s]	Kuwait
–	–	–	–	–	–	Lebanon

Table S6: Total researchers and researchers per million inhabitants, 2009 and 2013

	Researchers in full–time equivalents					
	2009			2013		
	Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants
Libya	–	–	–	–	–	–
Mauritania	–	–	–	–	–	–
Morocco	20 703[-1,q]	29.49[-1]	669[-1,q]	27 714[-2,q]	31.79[-2]	864[-2,q]
Oman	–	–	–	497[h]	23.54[h]	137[h]
Palestine	567	33.57[-2]	145	2 492[h]	–	576[h]
Qatar	–	–	–	1 203[-1]	20.23[-1]	587[-1]
Saudi Arabia	–	–	–	–	–	–
Sudan	–	–	–	–	–	–
Syrian Arab Rep.	–	–	–	–	–	–
Tunisia	13 300	–	1 265	15 159[-1]	–	1 394[-1]
United Arab Emirates	–	–	–	–	–	–
Yemen	–	–	–	–	–	–
Central Asia						
Kazakhstan	5 593	–	355	12 552[s]	–	763[s]
Kyrgyzstan	–	–	–	–	–	–
Mongolia	–	–	–	–	–	–
Tajikistan	–	–	–	–	–	–
Turkmenistan	–	–	–	–	–	–
Uzbekistan	–	–	–	15 029[-2,b]	39.14[-2]	534[-2,b]
South Asia						
Afghanistan	–	–	–	–	–	–
Bangladesh	–	–	–	–	–	–
Bhutan	–	–	–	–	–	–
India	154 827[-4]	14.85[-4,q]	137[-4]	192 819[-3]	14.28[-3]	160[-3]
Maldives	–	–	–	–	–	–
Nepal	1 500[-7,r]	–	62[-7,r]	–	–	–
Pakistan	27 602[h]	23.67	162[h]	30 244[h]	31.27[h]	166[h]
Sri Lanka	1 972[-1]	38.89[-1]	96[-1]	2 140[-3]	39.35[-3]	103[-3]
South–East Asia						
Brunei Darussalam	102[-5,q]	–	282[-5,q]	–	–	–
Cambodia	223[-7,q,r]	22.60[-7,q,r]	18[-7,q,r]	–	–	–
China	1 152 311	–	853	1 484 040	–	1 071
China, Hong Kong SAR	19 283	–	2 752	21 236[-1]	–	2 971[-1]
China, Macao SAR	300[q]	29.68[q]	575[q]	527[q]	32.18[q]	931[q]
Indonesia	21 349[q,r]	–	90[q,r]	–	–	–
Japan	655 530	–	5 147	660 489	–	5 195
Korea, DPR	–	–	–	–	–	–
Korea, Rep. of	244 077	–	5 068	321 842	–	6 533
Lao PDR	87[-7,q]	–	16[-7,q]	–	–	–
Malaysia	29 608	47.69	1 065	52 052[-1]	47.01[-1]	1 780[-1]
Myanmar	837[-7,q]	–	17[-7,q]	–	–	–
Philippines	6 957[-2]	50.81[-2]	78[-2]	–	–	–
Singapore	30 530	–	6 150	34 141[-1]	–	6 438[-1]
Thailand	22 000	50.29	332	36 360[-2]	53.10[-2]	546[-2]
Timor–Leste	–	–	–	–	–	–
Viet Nam	9 328[-7]	–	113[-7]	–	–	–
Oceania						
Australia	92 649[-1]	–	4 280[-1]	–	–	–
New Zealand	16 100	–	3 724	16 300[-2]	–	3 693[-2]
Cook Islands	–	–	–	–	–	–
Fiji	–	–	–	–	–	–
Kiribati	–	–	–	–	–	–
Marshall Islands	–	–	–	–	–	–
Micronesia	–	–	–	–	–	–
Nauru	–	–	–	–	–	–
Niue	–	–	–	–	–	–
Palau	–	–	–	–	–	–
Papua New Guinea	–	–	–	–	–	–
Samoa	–	–	–	–	–	–
Solomon Islands	–	–	–	–	–	–
Tonga	–	–	–	–	–	–
Tuvalu	–	–	–	–	–	–
Vanuatu	–	–	–	–	–	–

Source:
UNESCO Institute for Statistics (UIS), August, 2015

Sources for background data:
Population: United Nations, Department of Economic and Social Affairs, Population Division, 2013; World Population Prospects: The 2012 Revision

Researchers in head counts						
2009			2013			
Total researchers	Female researchers (%) *	Researchers per million inhabitants	Total researchers	Female researchers (%) *	Researchers per million inhabitants	
460[q]	24.75	77[q]	–	–	–	Libya
–	–	–	–	–	–	Mauritania
29 276[-1,q]	27.60[-1]	946[-1,q]	36 732[-2,q]	30.19[-2]	1 146[-2,q]	Morocco
–	–	–	1 235[h]	21.13[h]	340[h]	Oman
1 550	18.77	396	4 533[h]	22.59[h]	1 048[h]	Palestine
–	–	–	1 725[-1]	21.86[-1]	841[-1]	Qatar
1 271[k,q]	1.42	47[k,q]	–	–	–	Saudi Arabia
11 208[-4,b,r]	40.00[-4,r]	355[-4,b,r]	–	–	–	Sudan
–	–	–	–	–	–	Syrian Arab Rep.
28 274	–	2 690	30 127[-1]	–	2 770[-1]	Tunisia
–	–	–	–	–	–	United Arab Emirates
–	–	–	–	–	–	Yemen
						Central Asia
10 095	48.46	641	17 195[s]	51.46[s]	1 046[s]	Kazakhstan
2 290	43.45	435	2 224[-2]	43.21[-2]	412[-2]	Kyrgyzstan
1 748[q]	48.11[q]	654[q]	1 912[q]	48.90[q]	673[q]	Mongolia
1 722	38.79[-3]	231	2 152[h]	33.83	262[h]	Tajikistan
–	–	–	–	–	–	Turkmenistan
30 273	42.99	1 105	30 890[-2]	40.92[-2]	1 097[-2]	Uzbekistan
						South Asia
–	–	–	–	–	–	Afghanistan
–	–	–	–	–	–	Bangladesh
–	–	–	–	–	–	Bhutan
–	–	–	–	–	–	India
–	–	–	–	–	–	Maldives
3 000[-7,r]	15.00[-7,r]	124[-7,r]	5 123[-3,q,s]	7.79[-3]	191[-3,q,s]	Nepal
54 689[h]	26.97	322[h]	60 699[h]	29.78[h]	333[h]	Pakistan
4 037[-1]	39.86[-1]	197[-1]	5 162[-3]	36.92[-3]	249[-3]	Sri Lanka
						South–East Asia
244[-5,q]	40.57[-5]	676[-5,q]	–	–	–	Brunei Darussalam
744[-7,q,r]	20.70[-7,q,r]	59[-7,q,r]	–	–	–	Cambodia
–	–	–	2 069 650[-1]	–	1 503[-1]	China
23 014	–	3 284	24 934[-1]	–	3 488[-1]	China, Hong Kong SAR
658[q]	32.37[q]	1 261[q]	1 110[q]	34.50[q]	1 960[q]	China, Macao SAR
41 143[r]	30.58[-4]	173[q,r]	–	–	–	Indonesia
889 341	13.62	6 983	892 406	14.63	7 019	Japan
–	–	–	–	–	–	Korea, DPR
323 175	15.80	6 710	410 333	18.18	8 329	Korea, Rep. of
209[-7,q]	22.97[-7,r]	38[-7,q]	–	–	–	Lao PDR
53 304	50.91	1 918	75 257[-1]	49.92[-1]	2 574[-1]	Malaysia
4 725[-7,q]	85.46[-7,b]	96[-7,q]	–	–	–	Myanmar
11 490[-2]	52.25[-2]	129[-2]	–	–	–	Philippines
34 387	28.49	6 927	38 432[-1]	29.57[-1]	7 247[-1]	Singapore
38 506	51.08	581	51 178[-2]	52.66[-2]	769[-2]	Thailand
–	–	–	–	–	–	Timor–Leste
41 117[-7]	42.77[-7]	498[-7]	105 230[-2,s]	41.67[-2,s]	1 170[-2,s]	Viet Nam
						Oceania
–	–	–	–	–	–	Australia
27 000	51.99[-8]	6 246	28 100[-2]	–	6 366[-2]	New Zealand
–	–	–	–	–	–	Cook Islands
–	–	–	–	–	–	Fiji
–	–	–	–	–	–	Kiribati
–	–	–	–	–	–	Marshall Islands
–	–	–	–	–	–	Micronesia
19[-6,q]	15.79[-6,q]	1 925[-6,q,r]	–	–	–	Nauru
–	–	–	–	–	–	Niue
–	–	–	–	–	–	Palau
–	–	–	–	–	–	Papua New Guinea
–	–	–	–	–	–	Samoa
–	–	–	–	–	–	Solomon Islands
–	–	–	–	–	–	Tonga
–	–	–	–	–	–	Tuvalu
–	–	–	–	–	–	Vanuatu

Note:
* The year for the share of female researchers may not be the same as the year for total researchers for some countries.

N.B.: See Key To All Tables at the end of Table S10.

Table S7: Researchers by field of science, 2013 or closest year (%)

	Year	Researchers by field of science in head counts (%)								
		Natural sciences	Engineering and technology	Medical and health sciences	Agricultural sciences	Natural sciences and engineering	Social sciences	Humanities	Social sciences and humanities	Not elsewhere classified
North America										
Canada		–	–	–	–	–	–	–	–	–
United States of America		–	–	–	–	–	–	–	–	–
Latin America										
Argentina	2012	26.73	18.65	13.42	10.96	69.76	21.18	9.06	30.24	–
Belize		–	–	–	–	–	–	–	–	–
Bolivia	2010	25.41	21.32	15.84	15.23	77.80	16.54	5.67	22.20	–
Brazil		–	–	–	–	–	–	–	–	–
Chile	2008	21.36	25.91	16.94	12.31	76.52	18.20	5.26	23.48	–
Colombia	2012	18.72	11.38	15.67	6.42	52.19	36.83	7.66	44.49	3.32
Costa Rica	2011	8.07[h]	8.36[h]	7.59[h]	7.29[h]	31.32[h]	8.91[h]	1.82[h]	10.73[h]	57.96[d]
Ecuador	2011	14.63	20.14	11.27	11.37	57.41	35.09	7.50	42.59	–
El Salvador	2013	39.27	19.64	15.56	4.68	79.15	17.52	3.32	20.85	–
Guatemala	2012	20.42[q]	16.22[q]	19.82[q]	18.32[q]	74.77[q]	18.77[q]	6.46[q]	25.23[q]	–
Guyana		–	–	–	–	–	–	–	–	–
Honduras		–	–	–	–	–	–	–	–	–
Mexico	2003	16.71	35.43	12.34	9.58	74.07	17.40	8.53	25.93	–
Nicaragua		–	–	–	–	–	–	–	–	–
Panama	2008	19.65	8.21	14.69	5.62	48.16	17.93	–	17.93[q]	33.91
Paraguay	2008	13.18	15.06	12.24	20.94	61.41	23.29	9.88	33.18	5.41
Peru		–	–	–	–	–	–	–	–	–
Suriname		–	–	–	–	–	–	–	–	–
Uruguay	2013	28.80	10.45	12.78	15.36	67.37	23.26	9.28	32.54	0.08
Venezuela	2009	11.76[q]	13.11[q]	22.16[q]	16.75[q]	63.77[q]	36.23[q]	–	36.23[q]	–
Caribbean										
Antigua and Barbuda		–	–	–	–	–	–	–	–	–
Bahamas		–	–	–	–	–	–	–	–	–
Barbados		–	–	–	–	–	–	–	–	–
Cuba		–	–	–	–	–	–	–	–	–
Dominica		–	–	–	–	–	–	–	–	–
Dominican Rep.		–	–	–	–	–	–	–	–	–
Grenada		–	–	–	–	–	–	–	–	–
Haiti		–	–	–	–	–	–	–	–	–
Jamaica		–	–	–	–	–	–	–	–	–
St Kitts and Nevis		–	–	–	–	–	–	–	–	–
St Lucia		–	–	–	–	–	–	–	–	–
St Vincent and the Grenadines		–	–	–	–	–	–	–	–	–
Trinidad and Tobago	2012	24.73	29.54	14.44	10.50	79.21	20.79	–	20.79[q]	–
European Union										
Austria		–	–	–	–	–	–	–	–	–
Belgium		–	–	–	–	–	–	–	–	–
Bulgaria	2012	24.59	27.33	13.48	7.91	73.31	15.99	10.70	26.69	–
Croatia	2012	15.54	30.74	20.93	7.04	74.26	15.69	10.05	25.74	–
Cyprus	2012	28.32	24.45	4.96	2.98	60.71	25.34	13.95	39.29	–
Czech Rep.	2012	27.08	39.52	11.88	4.55	83.04	9.36	7.61	16.96	–
Denmark		–	–	–	–	–	–	–	–	–
Estonia	2012	24.88[h,r]	10.87[h,r]	6.75[h,r]	4.14[h,r]	46.63[h,r]	13.57[h,r]	13.09[h,r]	26.66[h,r]	26.71[d,r]
Finland		–	–	–	–	–	–	–	–	–
France		–	–	–	–	–	–	–	–	–
Germany		–	–	–	–	–	–	–	–	–
Greece	2011	14.98	34.49	21.23	5.22	75.91	12.12	11.97	24.09	–
Hungary	2012	26.87	33.35	10.85	5.18	76.24	13.23	10.54	23.76	–
Ireland		–	–	–	–	–	–	–	–	–
Italy		–	–	–	–	–	–	–	–	–
Latvia	2012	21.56[h,r]	19.01[h,r]	9.14[h,r]	5.90[h,r]	55.62[h,r]	19.34[h,r]	10.81[h,r]	30.14[h,r]	14.23[d,r]
Lithuania	2012	17.31[h,r]	14.73[h,r]	11.92[h,r]	2.74[h,r]	46.70[h,r]	26.77[h,r]	15.00[h,r]	41.77[h,r]	11.53[d,r]
Luxembourg		–	–	–	–	–	–	–	–	–
Malta	2012	23.57	27.98	14.40	2.89	68.85	16.47	9.44	25.91	5.24
Netherlands	2012	17.02	42.92	14.58	7.74	82.26	14.35	3.39	17.74	–
Poland	2012	18.35	32.15	14.66	5.89	71.05	16.45	12.50	28.95	–
Portugal	2012	21.92	29.62	16.51	2.72	70.77	18.13	11.10	29.23	–
Romania	2012	17.20	46.93	9.24	4.50	77.86	15.91	6.23	22.14	–
Slovakia	2013	16.55	32.74	12.33	4.11	65.73	20.29	13.98	34.27	–
Slovenia	2012	24.82	39.39	13.82	5.82	83.87	9.58	6.56	16.14	–
Spain		–	–	–	–	–	–	–	–	–
Sweden		–	–	–	–	–	–	–	–	–
United Kingdom		–	–	–	–	–	–	–	–	–
South-East Europe										
Albania	2008	8.66[q]	13.83[q]	9.06[q]	19.17[q]	50.73[q]	13.71[q]	35.56[q]	49.27[q]	–
Bosnia and Herzegovina	2013	16.55	40.48	2.49	14.30	73.82	19.68	5.46	25.14	1.04
Macedonia, FYR	2012	4.89	16.67	30.93	8.87	61.36	18.47	20.17	38.64	–
Montenegro	2011	6.73	21.67	28.53	4.27	61.19	18.82	19.99	38.81	–
Serbia	2012	20.58	23.95	9.37	13.37	67.27	19.02	13.71	32.73	–

	Year	Researchers by field of science in head counts (%)								
		Natural sciences	Engineering and technology	Medical and health sciences	Agricultural sciences	Natural sciences and engineering	Social sciences	Humanities	Social sciences and humanities	Not elsewhere classified
Other Europe and West Asia										
Armenia	2013	56.69[q]	14.11[q]	9.92[q]	1.16[q]	81.89[q]	5.61[q]	12.51[q]	18.11[q]	–
Azerbaijan	2013	32.78	16.09	11.11	6.65	66.63	13.36	20.01	33.37	–
Belarus	2013	18.59	61.00	4.77	5.76	90.12	7.52	2.36	9.88	–
Georgia	2005	29.34	14.95	9.90	11.33	65.52	9.38	19.08	28.46	6.02
Iran, Islamic Rep. of	2010	13.67[i]	25.14[i]	20.79[i]	18.78[i]	78.37[i]	21.63[c,i]	–[g,i]	21.63[i]	–[i]
Israel		–	–	–	–	–	–	–	–	–
Moldova, Rep. of	2013	35.94	13.78	14.06	12.34	76.12	12.65	11.23	23.88	–
Russian Federation	2013	23.19[q]	61.00[q]	4.43[q]	3.22[q]	91.84[q]	4.98[q]	3.18[q]	8.16[q]	–
Turkey	2013	10.06	35.86	22.13	4.50	72.55	18.39	9.06	27.45	–
Ukraine	2013	25.16	42.00	6.40	8.06	81.61	7.07	3.17	10.24	8.15
European Free Trade Assoc.										
Iceland		–	–	–	–	–	–	–	–	–
Liechtenstein		–	–	–	–	–	–	–	–	–
Norway	2012	–	–	–	–	76.06	–	–	23.70	0.24
Switzerland		–	–	–	–	–	–	–	–	–
Sub–Saharan Africa										
Angola	2011	23.14	18.62	9.24	12.96	63.97	30.97	5.06	36.03	–
Benin		–	–	–	–	–	–	–	–	–
Botswana	2012	37.54	11.01	22.61	20.00	91.16	2.17	0.14	2.32	6.52
Burkina Faso	2010	13.90	16.52	42.05	10.58	83.04	9.18	4.46	13.64	3.32
Burundi	2011	–	–	–	19.79[j]	19.79[q]	1.06[j]	–	1.06[q]	79.16[e]
Cabo Verde	2011	15.63[l,q]	35.94[l,q]	3.91[l,q]	1.56[l,q]	57.03[l,q]	22.66[l,q]	20.31[l,q]	42.97[l,q]	–
Cameroon		–	–	–	–	–	–	–	–	–
Central African Rep.	2009	36.57[q]	2.99[q]	13.43[q]	9.70[q]	62.69[q]	8.96[q]	24.63[q]	33.58[q]	3.73[q]
Chad		–	–	–	–	–	–	–	–	–
Comoros		–	–	–	–	–	–	–	–	–
Congo		–	–	–	–	–	–	–	–	–
Congo, Dem. Rep. of		–	–	–	–	–	–	–	–	–
Côte d'Ivoire		–	–	–	–	–	–	–	–	–
Djibouti		–	–	–	–	–	–	–	–	–
Equatorial Guinea		–	–	–	–	–	–	–	–	–
Eritrea		–	–	–	–	–	–	–	–	–
Ethiopia	2013	15.29	9.48	18.48	30.26	73.51	16.81	7.21	24.02	2.47
Gabon	2009	13.18[q]	4.71[q]	4.52[q]	8.10[q]	30.51[q]	22.41[q]	12.99[q]	35.40[q]	34.09[q]
Gambia	2011	–	–	40.00	60.00	100.00[q]	–	–	–	–
Ghana	2010	17.19	11.41	17.98	14.20	60.78	21.01	15.11	36.11	3.11
Guinea		–	–	–	–	–	–	–	–	–
Guinea–Bissau		–	–	–	–	–	–	–	–	–
Kenya	2010	3.67	13.73	25.45	40.51	83.37	9.45	7.19	16.63	–
Lesotho	2011	23.81[l,q]	19.05[l,q]	–	54.76[l,q]	97.62[l,q]	2.38[l,q]	–	2.38[l,q]	–
Liberia		–	–	–	–	–	–	–	–	–
Madagascar	2011	37.18	10.62	9.52	7.15	64.47	19.37	9.73	29.10	6.43
Malawi	2010	15.63[h]	20.18[h]	18.61[h]	16.93[h]	71.35[h]	18.45[h]	10.20[h]	28.65[h]	–
Mali	2006	46.04[q]	8.58[q]	13.59[q]	11.89[q]	80.10	13.03[q]	6.88[q]	19.90	–
Mauritius	2012	21.81[r]	10.20[r]	10.20[r]	33.71[r]	75.92[r]	16.43[r]	5.95[r]	22.38[r]	1.70[r]
Mozambique	2010	19.27	22.04	13.16	8.94	63.41	34.13	2.46	36.59	–
Namibia	2010	10.96	2.41	6.82	42.91	63.10	15.91	5.75	21.66	15.24
Niger		–	–	–	–	–	–	–	–	–
Nigeria		–	–	–	–	–	–	–	–	–
Rwanda		–	–	–	–	–	–	–	–	–
Sao Tome and Principe		–	–	–	–	–	–	–	–	–
Senegal	2010	18.00	1.98	19.60	1.60	41.19	50.67	6.40	57.07	1.74
Seychelles	2005	78.57	–	–	14.29	92.86[q]	–	–	–	7.14
Sierra Leone		–	–	–	–	–	–	–	–	–
Somalia		–	–	–	–	–	–	–	–	–
South Africa		–	–	–	–	–	–	–	–	–
South Sudan		–	–	–	–	–	–	–	–	–
Swaziland		–	–	–	–	–	–	–	–	–
Tanzania		–	–	–	–	–	–	–	–	–
Togo	2012	15.65[h]	6.10[h]	18.78[h]	14.71[h]	55.24[h]	2.35[h]	41.94[h]	44.29[h]	0.47[h]
Uganda	2010	17.43	12.15	10.06	11.52	51.17	37.38	11.45	48.83	–
Zambia		–	–	–	–	–	–	–	–	–
Zimbabwe	2012	30.05[h]	13.33[h]	0.18[h]	13.91[h]	57.47[h]	22.16[h]	15.48[h]	37.64[h]	4.89[h]
Arab states										
Algeria	2005	24.27[l,q]	37.63[q]	8.15[l,q]	8.40[q]	78.44[q]	9.40[l,q]	12.16[q]	21.56[q]	–
Bahrain	2013	8.24[l,q]	15.88[l,q]	43.53[l,q]	0.39[l,q]	68.04[l,q]	15.29[l,q]	5.69[l,q]	20.98[l,q]	10.98[l,q]
Egypt	2013	8.08[l]	7.20[l]	31.76[l]	4.12[l]	51.16[l]	16.83[l]	11.41[l]	28.24[l]	20.61[k]
Iraq	2011	17.75[b,h]	18.86[b,h]	12.39[b,h]	9.36[b,h]	58.35[b,h]	32.33[b,h]	9.30[b,h]	41.63[b,h]	0.02[h]
Jordan	2008	8.20	18.80	12.61	2.93	42.53	3.99	18.13	22.12	35.35
Kuwait	2013	14.34[h]	13.37[h]	11.85[h]	5.17[h]	44.72[h]	8.77[h]	13.34[h]	22.11[h]	33.17[h]
Lebanon		–	–	–	–	–	–	–	–	–
Libya		–	–	–	–	–	–	–	–	–

Table S7: Researchers by field of science, 2013 or closest year (%)

	Year	Researchers by field of science in head counts (%)								
		Natural sciences	Engineering and technology	Medical and health sciences	Agricultural sciences	Natural sciences and engineering	Social sciences	Humanities	Social sciences and humanities	Not elsewhere classified
Mauritania		–	–	–	–	–	–	–	–	–
Morocco	2011	33.71	7.56	10.40	1.80	53.46	26.10	20.44	46.54	–
Oman	2013	15.55[h]	13.04[h]	6.48[h]	25.26[h]	60.32h	24.29[h]	13.20[h]	37.49[h]	2.19[h]
Palestine	2013	16.55[h]	10.90[h]	5.85[h]	4.83[h]	38.12h	27.69[h]	34.19[h]	61.88[h]	–[h]
Qatar	2012	9.33	42.67	26.03	1.62	79.65	14.26	4.81	19.07	1.28
Saudi Arabia	2009	16.76[k]	43.04[k]	0.71[k]	2.60[k]	63.10k	–[k]	0.47[k]	0.47[k]	36.43[k]
Sudan	2005	17.86[r]	27.18[r]	22.29[r]	6.00[r]	73.32r	16.06[r]	8.10[r]	24.16[r]	2.52[r]
Syrian Arab Rep.		–	–	–	–	–	–	–	–	–
Tunisia		–	–	–	–	–	–	–	–	–
United Arab Emirates		–	–	–	–	–	–	–	–	–
Yemen		–	–	–	–	–	–	–	–	–
Central Asia										
Kazakhstan	2013	29.61	29.05	6.21	12.50	77.38	10.33	12.29	22.62	–
Kyrgyzstan	2011	26.66	25.49	17.67	9.53	79.36	6.92	11.65	18.57	2.07[r]
Mongolia	2013	37.45[q]	12.76[q]	9.94[q]	15.90[q]	76.05q	23.95[c,q]	–	23.95[q]	–
Tajikistan	2013	23.65	9.57	17.38	21.93	72.54	15.57	11.90	27.46	–
Turkmenistan		–	–	–	–	–	–	–	–	–
Uzbekistan	2011	22.37	16.13	11.85	6.06	56.40	22.07	21.53	43.60	–
South Asia										
Afghanistan		–	–	–	–	–	–	–	–	–
Bangladesh		–	–	–	–	–	–	–	–	–
Bhutan		–	–	–	–	–	–	–	–	–
India		–	–	–	–	–	–	–	–	–
Maldives		–	–	–	–	–	–	–	–	–
Nepal		–	–	–	–	–	–	–	–	–
Pakistan	2013	23.37[h]	17.45[h]	15.66[h]	13.03[h]	69.52h	17.12[h]	9.89[h]	27.01[h]	3.47[h]
Sri Lanka	2010	28.30	22.22	16.35	20.34	87.21	7.81[c]	–[g]	7.81	4.98
South–East Asia										
Brunei Darussalam		–	–	–	–	–	–	–	–	–
Cambodia		–	–	–	–	–	–	–	–	–
China		–	–	–	–	–	–	–	–	–
China, Hong Kong SAR		–	–	–	–	–	–	–	–	–
China, Macao SAR	2013	10.45	14.23	13.87	–	38.56q	41.80[q]	18.56[q]	60.36[q]	1.08[q]
Indonesia	2005	11.07[i]	11.12[i]	7.28[i]	13.39[i]	42.86i	18.16[i]	7.34[i]	25.50[i]	31.64
Japan	2013	18.27	47.92	14.57	4.33	85.08	5.90	3.37	11.52	3.40
Korea, DPR		–	–	–	–	–	–	–	–	–
Korea, Rep. of	2013	12.55	68.09	5.68	2.46	88.78	6.15	5.08	11.22	–
Lao PDR		–	–	–	–	–	–	–	–	–
Malaysia	2012	27.61	42.78	3.89	6.61	80.89	16.09	3.02	19.11	–
Myanmar	2002	14.12	34.41	4.68	1.82	55.03	42.46	2.52	44.97	–
Philippines	2007	15.63	34.87	8.18	22.42	81.11	15.22	2.32	17.55	1.35
Singapore	2012	16.31	61.04	16.63	2.05	96.02	–	–	–	3.98
Thailand	2011	8.97[h]	12.31[h]	12.57[h]	8.86[h]	42.72h	26.81[h]	2.62[h]	29.43[h]	27.86
Timor–Leste		–	–	–	–	–	–	–	–	–
Viet Nam		–	–	–	–	–	–	–	–	–
Oceania										
Australia		–	–	–	–	–	–	–	–	–
New Zealand		–	–	–	–	–	–	–	–	–
Cook Islands		–	–	–	–	–	–	–	–	–
Fiji		–	–	–	–	–	–	–	–	–
Kiribati		–	–	–	–	–	–	–	–	–
Marshall Islands		–	–	–	–	–	–	–	–	–
Micronesia		–	–	–	–	–	–	–	–	–
Nauru		–	–	–	–	–	–	–	–	–
Niue		–	–	–	–	–	–	–	–	–
Palau		–	–	–	–	–	–	–	–	–
Papua New Guinea		–	–	–	–	–	–	–	–	–
Samoa		–	–	–	–	–	–	–	–	–
Solomon Islands		–	–	–	–	–	–	–	–	–
Tonga		–	–	–	–	–	–	–	–	–
Tuvalu		–	–	–	–	–	–	–	–	–
Vanuatu		–	–	–	–	–	–	–	–	–

Source: UNESCO Institute for Statistics (UIS), August, 2015

N.B.: See Key To All Tables at the end of Table S10.

Table S8: Scientific publications by country, 2005-2014

	Number of publications										Publications per million inhabitants	
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2008	2014
North America												
Canada	39 879	42 648	43 917	46 829	48 713	49 728	51 508	51 459	54 632	54 631	1 403	1 538
United States of America	267 521	275 884	280 806	289 769	294 630	301 826	312 374	306 688	324 047	321 846	945	998
Latin America												
Argentina	5 056	5 429	5 767	6 406	6 779	7 234	7 664	7 657	8 060	7 885	161	189
Belize	12	12	6	8	5	13	12	13	19	16	27	47
Bolivia	120	131	179	192	184	173	186	155	212	207	20	19
Brazil	17 106	19 102	23 621	28 244	30 248	31 449	34 006	34 165	37 041	37 228	147	184
Chile	2 912	3 090	3 429	3 737	4 254	4 477	5 008	5 320	5 604	6 224	222	350
Colombia	871	1 040	1 333	1 967	2 155	2 503	2 790	2 957	3 189	2 997	44	61
Costa Rica	302	304	316	389	381	394	413	379	391	474	86	96
Ecuador	203	200	263	281	349	295	299	369	425	511	19	32
El Salvador	20	17	15	18	23	34	42	41	32	42	3	7
Guatemala	63	52	65	63	87	94	85	105	115	101	5	6
Guyana	18	8	17	17	10	23	14	16	18	23	22	29
Honduras	25	30	23	30	34	39	46	49	56	35	4	4
Mexico	6 899	6 992	7 891	8 559	8 738	9 047	9 842	10 093	10 957	11 147	74	90
Nicaragua	39	55	37	55	50	62	57	70	52	54	10	9
Panama	156	191	226	250	244	294	292	325	343	326	70	83
Paraguay	28	29	39	34	37	54	65	58	67	57	5	8
Peru	334	387	452	499	539	551	621	633	713	783	17	25
Suriname	13	6	6	7	6	6	7	22	22	11	14	20
Uruguay	425	441	463	582	605	603	733	653	728	824	174	241
Venezuela	1 097	1 125	1 128	1 325	1 200	1 174	1 040	913	1 010	788	47	26
Caribbean												
Antigua and Barbuda	5	4	5	7	2	4	1	2	4	1	82	11
Bahamas	8	9	17	12	12	12	20	17	26	33	34	86
Barbados	44	42	39	50	41	52	67	63	55	52	180	182
Cuba	662	713	733	804	772	717	818	804	817	749	71	67
Dominica	5	2	6	2	4	12	10	9	10	10	28	138
Dominican Rep.	20	19	26	34	26	39	45	52	63	49	3	5
Grenada	17	30	57	72	83	81	95	112	106	152	693	1 430
Haiti	14	23	16	20	18	24	48	39	48	60	2	6
Jamaica	136	126	143	157	159	169	177	178	151	117	58	42
St Kitts and Nevis	1	3	1	3	9	10	6	14	20	40	59	730
St Lucia	2	2	2	1	0	9	2	1	2	0	6	0
St Vincent and the Grenadines	0	2	1	0	1	3	2	3	1	2	0	18
Trinidad and Tobago	136	110	137	142	154	152	169	161	149	146	108	109
European Union												
Austria	8 644	8 865	9 502	10 049	10 407	11 127	11 939	11 746	12 798	13 108	1 205	1 537
Belgium	12 572	12 798	13 611	14 467	15 071	15 962	16 807	16 719	18 119	18 208	1 343	1 634
Bulgaria	1 756	1 743	2 241	2 266	2 310	2 172	2 153	2 244	2 266	2 065	302	288
Croatia	1 624	1 705	2 037	2 391	2 739	2 897	3 182	3 103	3 004	2 932	548	686
Cyprus	258	302	346	408	508	610	638	707	855	814	379	706
Czech Rep.	5 799	6 535	7 157	7 783	8 206	8 835	9 222	9 324	9 998	10 781	748	1 004
Denmark	8 747	9 116	9 411	9 817	10 257	11 285	12 387	12 763	13 982	14 820	1 786	2 628
Estonia	745	783	943	952	1 055	1 189	1 286	1 290	1 513	1 567	728	1 221
Finland	7 987	8 475	8 542	8 814	8 928	9 274	9 666	9 571	10 206	10 758	1 657	1 976
France	52 476	54 516	55 254	59 304	60 893	61 626	63 418	62 371	66 057	65 086	948	1 007
Germany	73 573	75 191	76 754	79 402	82 452	85 095	88 836	88 322	92 975	91 631	952	1 109
Greece	7 597	8 729	9 294	9 706	10 028	9 987	10 141	9 929	9 871	9 427	876	847
Hungary	4 864	5 007	5 053	5 541	5 330	5 023	5 619	5 739	5 931	6 059	552	610
Ireland	3 941	4 375	4 613	5 161	5 519	6 173	6 552	6 244	6 691	6 576	1 186	1 406
Italy	40 111	42 396	44 810	47 139	49 302	50 069	52 290	52 679	57 943	57 472	787	941
Latvia	319	298	369	420	406	395	555	528	592	586	196	287
Lithuania	885	1 127	1 666	1 714	1 668	1 660	1 899	1 793	1 768	1 827	545	607
Luxembourg	175	208	223	327	398	472	594	613	755	854	671	1 591
Malta	61	60	76	109	96	111	122	151	207	207	259	481
Netherlands	22 225	22 971	23 505	24 646	26 500	28 148	29 396	30 018	32 172	31 823	1 493	1 894
Poland	13 843	15 129	16 032	18 210	18 506	19 172	20 396	21 486	22 822	23 498	477	615
Portugal	5 245	6 455	6 238	7 448	8 196	8 903	9 992	10 679	11 953	11 855	705	1 117
Romania	2 543	2 934	3 983	5 165	6 100	6 628	6 485	6 657	7 550	6 651	235	307
Slovakia	1 931	2 264	2 473	2 709	2 635	2 758	2 856	2 883	2 989	3 144	500	576
Slovenia	2 025	2 081	2 396	2 795	2 840	2 912	3 265	3 265	3 458	3 301	1 375	1 590
Spain	29 667	32 130	34 558	37 078	39 735	41 828	45 318	46 435	49 435	49 247	820	1 046
Sweden	16 445	16 895	17 184	17 270	17 981	18 586	19 403	19 898	21 611	21 854	1 870	2 269
United Kingdom	70 201	73 377	75 763	77 116	78 867	81 553	84 360	83 405	89 429	87 948	1 257	1 385
South–East Europe												
Albania	37	30	39	58	65	88	146	127	144	154	18	48
Bosnia and Herzegovina	91	91	252	278	286	360	398	347	312	323	72	84
Macedonia,FYR	106	134	179	201	211	235	263	273	282	330	96	157
Montenegro	42	59	64	94	102	130	155	152	171	191	152	307
Serbia	1 600	1 741	2 303	2 783	3 327	3 659	4 244	5 064	4 941	4 764	285	503
Other Europe and West Asia												
Armenia	381	404	418	560	497	574	670	775	705	691	188	232
Azerbaijan	237	238	227	299	389	457	522	497	424	425	34	45
Belarus	978	945	914	1 033	998	964	1 067	1 133	1 046	1 077	108	116
Georgia	305	363	327	338	358	381	485	570	515	527	77	122
Iran,Islamic Rep. of	4 676	6 148	9 020	11 244	14 460	16 951	21 509	23 092	24 713	25 588	155	326

Table S8: Scientific publications by country, 2005-2014

	Number of publications										Publications per million inhabitants	
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2008	2014
Israel	9 884	10 395	10 351	10 576	10 371	10 541	10 853	10 665	11 066	11 196	1 488	1 431
Moldova,Rep. of	213	222	180	228	258	227	258	230	242	248	63	72
Russian Federation	24 694	24 068	25 606	27 418	27 861	26 869	28 285	26 183	28 649	29 099	191	204
Turkey	13 830	14 734	17 281	18 493	20 657	21 374	22 065	22 251	23 897	23 596	263	311
Ukraine	4 029	3 935	4 205	5 020	4 450	4 445	4 909	4 601	4 834	4 895	108	109
European Free Trade Assoc.												
Iceland	427	458	490	575	623	753	716	810	866	864	1 858	2 594
Liechtenstein	33	36	37	46	41	50	41	55	48	52	1 293	1 398
Norway	6 090	6 700	7 057	7 543	8 110	8 499	9 327	9 451	9 947	10 070	1 579	1 978
Switzerland	16 397	17 809	18 341	19 131	20 336	21 361	22 894	23 205	25 051	25 308	2 500	3 102
Sub–Saharan Africa												
Angola	17	13	15	15	32	29	28	36	40	45	1	2
Benin	86	121	132	166	174	194	221	228	253	270	18	25
Botswana	112	152	148	162	133	114	175	156	171	210	84	103
Burkina Faso	116	159	149	193	214	220	268	296	241	272	13	16
Burundi	8	5	14	8	9	20	19	16	17	18	1	2
Cabo Verde	1	6	1	3	10	15	2	11	19	25	6	50
Cameroon	303	395	431	482	497	561	579	553	652	706	25	31
Central African Rep.	20	20	21	17	24	22	23	29	29	32	4	7
Chad	21	25	12	14	18	11	20	13	14	26	1	2
Comoros	3	0	6	3	1	3	6	3	2	0	5	0
Congo	56	81	86	69	77	89	86	92	84	111	18	24
Congo,Dem. Rep. of	21	14	26	38	69	82	109	119	144	114	1	2
Côte d'Ivoire	110	128	155	183	201	205	216	238	194	208	10	10
Djibouti	2	2	3	2	6	6	9	7	6	15	2	17
Equatorial Guinea	1	2	2	2	5	4	5	5	2	4	3	5
Eritrea	26	29	29	15	19	11	13	3	17	22	3	3
Ethiopia	281	293	382	402	484	514	630	638	790	865	5	9
Gabon	70	78	79	82	88	86	117	94	113	137	55	80
Gambia	68	97	71	95	87	97	73	100	111	124	60	65
Ghana	208	227	276	293	333	427	421	477	546	579	13	22
Guinea	12	30	22	16	23	27	23	25	35	49	2	4
Guinea–Bissau	19	17	27	20	19	21	24	22	29	37	13	21
Kenya	571	690	763	855	892	1 035	1 196	1 131	1 244	1 374	22	30
Lesotho	5	14	11	12	21	18	23	26	19	16	6	8
Liberia	4	4	0	6	1	8	8	9	13	11	2	3
Madagascar	114	140	158	152	156	166	182	181	209	188	8	8
Malawi	116	129	183	218	199	244	280	296	296	322	15	19
Mali	71	97	82	93	112	126	149	170	142	141	7	9
Mauritius	49	51	42	44	49	70	61	85	90	89	36	71
Mozambique	55	60	79	84	95	100	157	134	137	158	4	6
Namibia	80	76	65	64	77	57	92	96	121	139	30	59
Niger	68	66	68	81	75	78	94	81	81	108	5	6
Nigeria	1 001	1 150	1 608	1 977	2 076	2 258	2 098	1 756	1 654	1 961	13	11
Rwanda	13	25	36	34	58	66	90	85	114	143	3	12
Sao Tome and Principe	0	2	1	1	1	3	1	1	1	3	6	15
Senegal	210	188	229	228	258	279	343	349	340	338	19	23
Seychelles	12	21	25	21	18	19	31	31	44	34	234	364
Sierra Leone	5	4	7	12	18	23	25	26	29	45	2	7
Somalia	0	2	0	1	3	2	2	2	3	7	0	1
South Africa	4 235	4 711	5 152	5 611	6 212	6 628	7 682	7 934	8 790	9 309	112	175
South Sudan	1	5	3	5	15	8	8	9	8	0	1	0
Swaziland	22	10	18	21	26	52	41	33	40	25	18	20
Tanzania	323	396	428	426	506	541	552	557	666	770	10	15
Togo	34	36	38	44	38	50	68	47	55	61	7	9
Uganda	244	294	406	403	485	577	644	625	702	757	13	19
Zambia	96	116	130	134	130	170	203	204	230	245	11	16
Zimbabwe	173	178	219	217	188	199	227	240	257	310	17	21
Arab states												
Algeria	795	977	1 190	1 339	1 597	1 658	1 758	1 842	2 081	2 302	37	58
Bahrain	93	117	121	114	135	129	130	122	166	155	102	115
Egypt	2 919	3 202	3 608	4 147	4 905	5 529	6 657	6 960	7 613	8 428	55	101
Iraq	89	124	180	195	253	279	352	482	735	841	7	24
Jordan	641	673	835	989	1 022	1 038	1 009	976	1 099	1 093	167	146
Kuwait	526	541	571	659	631	635	637	546	618	604	244	174
Lebanon	462	555	549	621	640	690	701	810	938	1 009	148	203
Libya	70	90	107	126	125	159	123	141	162	181	21	29
Mauritania	27	20	20	14	19	15	21	23	23	23	4	6
Morocco	990	1 009	1 088	1 214	1 236	1 355	1 474	1 496	1 579	1 574	39	47
Oman	283	277	323	327	365	383	447	444	505	591	126	151
Palestine	72	68	75	65	62	52	66	70	85	14	17	3
Qatar	109	128	168	217	238	339	407	517	817	1 242	160	548
Saudi Arabia	1 362	1 450	1 574	1 910	2 273	3 551	5 773	7 226	8 903	10 898	72	371
Sudan	120	110	147	150	215	282	283	244	274	309	4	8
Syrian Arab Rep.	168	153	192	218	211	318	340	304	304	229	11	10
Tunisia	1 214	1 503	1 749	2 068	2 439	2 607	2 900	2 739	2 866	3 068	199	276
United Arab Emirates	530	601	621	713	842	888	1 057	1 096	1 277	1 450	105	154
Yemen	41	52	57	64	106	114	164	162	175	202	3	8

	Number of publications										Publications per million inhabitants	
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2008	2014
Central Asia												
Kazakhstan	200	210	255	221	269	247	276	330	499	600	14	36
Kyrgyzstan	46	47	51	54	51	57	65	67	95	82	10	15
Mongolia	67	71	99	126	166	173	145	167	209	203	48	70
Tajikistan	32	32	45	49	39	51	53	61	67	46	7	5
Turkmenistan	5	6	8	3	6	9	12	19	13	24	1	5
Uzbekistan	296	289	335	306	350	328	363	284	313	323	11	11
South Asia												
Afghanistan	7	10	8	23	19	36	31	39	34	44	1	1
Bangladesh	511	584	669	797	881	995	1 079	1 216	1 302	1 394	5	9
Bhutan	8	23	5	8	16	27	28	23	35	36	12	47
India	24 703	27 785	32 610	37 228	38 967	41 983	45 961	46 106	50 691	53 733	32	42
Maldives	1	2	5	4	5	5	5	8	5	16	13	46
Nepal	158	212	218	253	295	349	336	365	457	455	10	16
Pakistan	1 142	1 553	2 534	3 089	3 614	4 522	5 629	5 522	6 392	6 778	18	37
Sri Lanka	283	279	322	430	432	419	461	475	489	599	21	28
South–East Asia												
Brunei Darussalam	29	31	37	43	48	49	46	64	79	106	111	250
Cambodia	54	70	92	86	126	139	136	168	191	206	6	13
China	66 151	79 740	89 068	102 368	118 749	131 028	153 446	170 189	205 268	256 834	76	184
China,Hong Kong SAR	7 220	7 592	7 440	7 660	8 141	8 527	9 258	9 133	9 725	852	1 099	117
China,Macao SAR	63	96	79	121	143	201	226	368	488	46	238	80
Indonesia	554	612	629	709	893	992	1 103	1 222	1 426	1 476	3	6
Japan	76 950	77 083	75 801	76 244	75 606	74 203	75 924	72 769	75 870	73 128	599	576
Korea,DPR	11	10	11	36	29	34	19	37	21	23	1	1
Korea,Rep. of	25 944	28 202	28 750	33 431	36 659	40 156	43 836	45 765	48 663	50 258	698	1 015
Lao PDR	36	55	47	58	60	95	114	133	126	129	9	19
Malaysia	1 559	1 813	2 225	2 852	4 266	5 777	7 607	7 738	8 925	9 998	104	331
Myanmar	41	41	42	39	43	47	56	52	59	70	1	1
Philippines	486	494	578	663	706	730	873	779	894	913	7	9
Singapore	6 111	6 493	6 457	7 075	7 669	8 459	9 032	9 430	10 280	10 553	1 459	1 913
Thailand	2 503	3 089	3 710	4 335	4 812	5 214	5 790	5 755	6 378	6 343	65	94
Timor–Leste	2	8	3	0	3	3	0	4	6	1	0	1
Viet Nam	570	656	750	943	963	1 207	1 387	1 669	2 105	2 298	11	25
Oceania												
Australia	24 755	27 049	28 649	30 922	33 284	35 228	38 505	39 899	44 926	46 639	1 429	1 974
New Zealand	4 942	5 119	5 373	5 681	5 854	6 453	6 811	6 917	7 303	7 375	1 328	1 620
Cook Islands	1	1	3	0	0	2	3	4	6	7	0	446
Fiji	61	67	67	65	62	59	74	83	98	106	77	120
Kiribati	0	2	2	0	0	0	1	0	3	5	0	48
Marshall Islands	1	5	0	1	6	1	1	5	1	5	19	95
Micronesia	4	7	7	3	9	9	3	7	6	12	29	115
Nauru	0	0	0	0	0	0	1	0	0	1	0	93
Niue	0	0	1	0	0	0	0	0	0	3	0	2 214
Palau	7	9	11	4	6	4	7	5	8	12	197	571
Papua New Guinea	44	51	84	78	76	81	100	112	89	110	12	15
Samoa	3	9	1	1	0	0	0	3	1	4	5	21
Solomon Islands	6	7	8	4	6	11	17	8	11	17	8	30
Tonga	0	4	5	4	2	3	6	2	1	6	39	57
Tuvalu	0	1	0	0	0	0	0	1	1	3	0	264
Vanuatu	12	9	7	9	16	12	21	18	19	19	40	74

Source: data from Thomson Reuters' Web of Science, Science Citation Index Expanded, compiled for UNESCO by Science–Metrix, May 2015

Sources for background data:
Population: United Nations, Department of Economic and Social Affairs, Population Division, 2013; *World Population Prospects: The 2012 Revision*

Table S9: Publications by major field of science, 2008 and 2014

	Publications by field of science													
	Total		Agricultural sciences		Astronomy		Biological sciences		Chemistry		Computer sciences		Engineering	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
North America														
Canada	46 829	54 631	1 192	1 347	614	833	10 136	9 723	3 144	3 269	1 109	1 274	4 527	5 346
United States of America	289 769	321 846	5 165	5 121	4 405	5 068	71 105	65 773	20 000	21 500	5 460	5 909	21 155	23 863
Latin America														
Argentina	6 406	7 885	331	407	132	155	1 788	1 906	696	663	49	103	388	540
Belize	8	16	1	0	0	0	1	3	0	0	0	0	0	0
Bolivia	192	207	11	9	6	0	77	75	8	2	0	0	4	6
Brazil	28 244	37 228	2 508	3 150	207	340	6 024	7 113	2 088	2 695	244	510	1 689	2 478
Chile	3 737	6 224	148	204	370	807	728	918	298	350	68	148	265	396
Colombia	1 967	2 997	128	120	4	12	341	485	160	221	16	38	112	297
Costa Rica	389	474	15	28	1	2	157	171	10	19	2	3	10	12
Ecuador	281	511	10	28	1	1	90	147	3	23	0	7	4	36
El Salvador	18	42	0	1	0	0	9	9	0	0	0	0	0	0
Guatemala	63	101	3	4	0	0	23	25	0	1	0	0	1	2
Guyana	17	23	0	0	0	0	4	5	1	2	1	0	0	0
Honduras	30	35	2	2	0	0	6	10	0	0	1	0	0	0
Mexico	8 559	11 147	365	561	214	289	1 984	2 320	718	828	85	243	756	1 051
Nicaragua	55	54	1	2	0	0	11	14	1	0	0	0	0	0
Panama	250	326	2	13	2	1	151	143	3	1	0	1	0	2
Paraguay	34	57	1	2	0	1	15	19	0	1	0	2	0	2
Peru	499	783	19	32	1	0	150	215	9	13	3	3	14	26
Suriname	7	11	0	0	0	0	3	1	0	0	0	0	0	2
Uruguay	582	824	43	92	3	1	157	232	57	58	8	22	23	26
Venezuela	1 325	788	65	74	12	22	300	175	135	62	13	9	107	61
Caribbean														
Antigua and Barbuda	7	1	0	0	0	0	2	0	0	0	0	0	0	0
Bahamas	12	33	0	0	0	0	5	11	0	0	0	0	0	0
Barbados	50	52	1	0	0	0	15	5	3	7	3	1	0	1
Cuba	804	749	84	31	2	6	195	179	99	46	6	31	62	61
Dominica	2	10	0	0	0	0	0	5	0	0	0	0	0	0
Dominican Rep.	34	49	2	2	0	0	12	15	1	1	0	0	1	2
Grenada	72	152	1	4	0	0	25	51	1	1	0	1	0	0
Haiti	20	60	0	1	0	0	3	15	2	0	0	0	1	0
Jamaica	157	117	6	8	0	0	19	38	8	10	0	0	7	0
St Kitts and Nevis	3	40	0	1	0	0	0	10	0	0	0	0	0	1
St Lucia	1	0	0	0	0	0	1	0	0	0	0	0	0	0
St Vincent and the Grenadines	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Trinidad and Tobago	142	146	5	12	1	0	27	21	5	12	0	4	9	12
European Union														
Austria	10 049	13 108	139	206	171	248	2 009	2 246	771	915	216	329	786	1 015
Belgium	14 467	18 208	413	492	213	418	3 032	3 214	1 225	1 417	272	338	1 103	1 440
Bulgaria	2 266	2 065	84	36	50	46	334	274	379	281	25	28	152	137
Croatia	2 391	2 932	77	117	15	51	367	436	241	232	16	42	237	265
Cyprus	408	814	4	19	3	4	48	85	40	57	26	27	68	103
Czech Rep.	7 783	10 781	253	342	123	159	1 691	2 054	1 142	1 422	163	249	650	923
Denmark	9 817	14 820	344	454	103	380	2 445	2 923	577	905	102	186	604	968
Estonia	952	1 567	31	57	20	27	242	355	73	126	15	24	92	122
Finland	8 814	10 758	207	201	131	224	2 018	1 981	622	739	186	285	683	1 074
France	59 304	65 086	1 093	1 151	1 251	1 690	10 855	10 456	6 242	6 144	1 181	1 622	5 245	5 804
Germany	79 402	91 631	1 450	1 505	1 757	2 466	15 133	15 314	8 698	9 119	1 035	1 404	5 812	6 982
Greece	9 706	9 427	299	257	82	146	1 361	1 161	726	637	362	402	1 131	956
Hungary	5 541	6 059	95	116	58	112	1 143	1 119	716	587	79	110	279	330
Ireland	5 161	6 576	293	363	95	119	1 023	1 114	404	476	115	132	380	528
Italy	47 139	57 472	1 095	1 455	1 044	1 414	8 347	8 635	3 850	3 991	950	1 171	3 825	5 280
Latvia	420	586	9	29	5	4	52	82	49	91	8	11	90	92
Lithuania	1 714	1 827	70	65	23	33	140	157	99	143	63	41	362	288
Luxembourg	327	854	3	15	0	1	85	160	19	51	11	55	42	76
Malta	109	207	0	4	0	3	17	29	0	8	2	4	9	19
Netherlands	24 646	31 823	528	656	493	812	5 255	5 634	1 468	1 554	416	461	1 550	1 882
Poland	18 210	23 498	606	823	254	368	2 707	3 569	2 793	3 244	197	381	2 152	2 281
Portugal	7 448	11 855	256	358	89	166	1 358	2 013	1 073	1 243	145	312	918	1 476
Romania	5 165	6 651	37	72	20	65	194	510	688	703	143	142	517	736
Slovakia	2 709	3 144	96	90	49	81	475	496	341	353	49	78	280	314
Slovenia	2 795	3 301	64	85	19	28	427	431	305	309	67	101	402	445
Spain	37 078	49 247	1 703	2 021	712	1 185	7 142	8 203	4 609	4 971	952	1 712	3 335	4 751
Sweden	17 270	21 854	264	295	183	333	4 056	4 071	1 206	1 441	205	320	1 314	2 046
United Kingdom	77 116	87 948	1 048	917	1 708	2 360	16 883	16 360	5 556	5 629	1 335	1 732	5 601	6 704
South-East Europe														
Albania	58	154	3	7	1	0	6	19	0	6	0	1	3	5
Bosnia and Herzegovina	278	323	4	11	0	1	18	43	1	7	1	8	21	34
Macedonia, FYR	201	330	3	16	0	1	38	59	27	18	2	9	11	35
Montenegro	94	191	2	5	1	2	7	18	0	4	2	1	20	27
Serbia	2 783	4 764	44	186	24	49	324	456	223	346	52	121	314	613
Other Europe and West Asia														
Armenia	560	691	0	3	30	23	37	35	66	64	2	3	59	34
Azerbaijan	299	425	1	1	5	4	4	16	75	59	2	4	25	28
Belarus	1 033	1 077	0	6	1	0	69	70	178	143	1	8	161	105

	Publications by field of science															
	Geosciences		Mathematics		Medical sciences		Other life sciences		Physics		Psychology		Social sciences		Unclassified articles	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
	4 095	4 579	1 583	1 471	12 819	15 207	548	623	3 675	3 248	642	660	404	522	2 341	6 529
	17 704	20 386	8 533	8 498	86 244	92 957	3 858	4 043	25 916	22 591	3 258	3 583	2 414	2 681	14 552	39 873
	613	801	203	198	927	1 120	9	10	720	658	35	43	23	50	492	1 231
	3	2	0	0	0	5	1	1	0	0	0	0	0	1	2	4
	25	33	0	0	31	26	0	0	5	6	1	1	6	2	18	47
	1 215	1 977	646	908	6 393	7 683	294	320	2 428	2 542	119	172	97	150	4 292	7 190
	417	616	192	259	638	966	21	26	302	546	16	34	8	46	266	908
	77	153	49	97	268	436	18	9	225	438	5	15	12	19	552	657
	32	43	5	5	57	64	1	1	9	19	0	9	4	3	86	95
	50	65	2	5	45	67	1	0	51	30	2	1	1	0	21	101
	4	4	0	0	3	19	1	0	1	0	0	0	0	0	0	9
	4	2	0	0	24	36	1	0	1	0	0	0	2	1	4	30
	0	8	0	0	5	3	0	1	0	0	0	1	0	1	6	2
	1	3	0	0	11	11	3	0	1	0	0	0	1	1	4	8
	788	892	261	321	1 160	1 383	20	13	1 166	1 177	62	63	39	52	941	1 954
	17	9	0	0	13	13	3	0	1	0	0	0	0	0	8	16
	36	40	0	0	16	35	1	0	0	2	3	10	2	2	34	76
	0	4	0	1	12	11	0	0	0	0	0	0	0	0	6	14
	72	90	3	11	152	177	8	0	13	37	2	4	8	12	45	163
	1	1	0	0	2	4	0	0	0	1	0	0	0	0	1	2
	60	60	17	30	122	139	0	2	42	42	6	8	0	4	44	108
	61	38	63	44	167	106	3	1	106	51	2	2	2	3	289	140
	0	1	0	0	5	0	0	0	0	0	0	0	0	0	0	0
	3	11	0	2	2	2	0	0	0	0	1	1	1	1	0	5
	4	11	1	1	17	12	1	1	3	2	0	1	0	0	2	10
	36	51	19	16	123	137	2	0	79	77	1	0	3	2	93	112
	0	1	0	0	0	2	0	0	1	0	0	0	0	0	1	2
	3	4	0	0	9	14	0	0	0	0	0	0	0	0	6	11
	2	12	0	0	40	51	0	1	0	0	0	1	0	1	3	29
	1	5	0	0	12	22	0	0	0	0	0	2	0	1	1	14
	12	9	4	3	85	28	0	2	0	2	0	0	2	0	14	17
	0	1	0	0	3	16	0	0	0	0	0	0	0	0	0	11
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	22	16	1	1	45	33	0	0	0	0	1	4	6	3	20	28
	646	865	383	476	3 040	3 553	18	28	1 154	1 251	77	104	70	108	569	1 764
	873	1 011	475	429	4 213	5 065	76	93	1 585	1 607	124	168	109	161	754	2 355
	96	87	89	89	209	186	3	4	326	293	3	2	2	1	514	601
	183	207	110	123	432	547	12	28	213	332	2	6	6	10	480	536
	21	87	42	43	48	122	5	16	67	128	2	7	5	8	29	108
	495	744	375	480	1 191	1 390	5	14	1 079	1 435	26	24	64	62	526	1 483
	805	1 083	168	199	3 177	4 487	44	100	859	908	68	107	69	122	452	1 998
	122	163	26	22	124	182	6	6	127	222	3	16	1	9	70	236
	630	816	202	275	2 445	2 376	88	122	972	1 018	84	95	62	112	484	1 440
	4 129	5 195	2 817	2 970	13 035	12 800	81	89	8 888	7 997	393	372	298	403	3 796	8 393
	4 473	5 738	2 417	2 689	21 459	22 170	150	188	11 867	10 439	600	682	422	667	4 129	12 268
	659	808	316	315	2 935	2 543	42	37	953	948	30	38	74	71	736	1 108
	214	305	355	315	1 130	1 199	12	18	753	840	38	42	17	30	652	936
	296	402	156	131	1 387	1 668	91	99	567	597	33	48	36	48	285	851
	2 824	3 654	1 767	1 946	13 661	15 724	128	176	6 058	5 559	247	264	254	405	3 089	7 798
	15	18	12	10	49	69	0	2	93	77	4	4	0	4	34	93
	72	123	86	65	127	200	3	5	248	298	1	3	2	16	418	390
	22	64	18	58	76	137	1	2	26	74	2	6	3	6	19	149
	18	16	5	9	32	63	5	3	8	8	0	1	0	0	13	40
	1 407	1 916	429	399	8 989	11 266	238	290	1 992	1 908	420	465	253	398	1 208	4 182
	963	1 538	770	950	2 593	3 528	13	26	3 171	3 119	25	46	29	77	1 937	3 548
	775	1 131	310	414	984	1 696	17	52	921	1 133	42	75	43	117	517	1 669
	191	349	485	595	374	663	24	32	806	981	3	8	36	60	1 647	1 735
	148	153	123	113	284	340	1	15	472	607	8	3	16	9	367	492
	103	183	139	164	420	460	8	18	396	458	4	20	11	20	430	579
	2 609	3 717	1 491	1 673	8 026	9 557	99	219	4 046	3 927	215	381	242	421	1 897	6 509
	1 195	1 516	374	407	5 319	6 059	296	300	1 724	1 755	136	150	138	178	860	2 983
	5 095	6 099	1 941	2 132	22 842	24 213	953	1 002	7 806	7 074	1 088	1 066	1 008	1 154	4 252	11 506
	18	18	1	8	12	33	0	1	1	0	0	0	0	4	13	52
	5	12	9	23	45	52	0	1	17	21	1	0	0	0	156	110
	13	15	8	13	27	61	0	0	26	21	0	2	0	1	46	79
	3	18	2	11	6	14	0	0	16	9	0	1	0	1	35	80
	85	188	190	230	426	637	3	10	326	515	3	11	2	13	767	1 389
	6	8	44	44	41	28	0	1	250	406	0	2	1	2	24	38
	12	18	36	47	12	9	0	0	99	176	1	0	0	3	27	60
	21	21	52	43	54	46	1	3	317	442	0	1	1	1	177	188

Table S9: Publications by major field of science, 2008 and 2014

	Publications by field of science													
	Total		Agricultural sciences		Astronomy		Biological sciences		Chemistry		Computer sciences		Engineering	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
Georgia	338	527	0	6	15	27	32	38	30	19	3	1	12	20
Iran, Islamic Rep. of	11 244	25 588	544	839	23	106	1 154	2 142	1 965	3 603	266	855	1 740	5 474
Israel	10 576	11 196	165	154	152	240	2 162	1 974	751	765	442	413	639	646
Moldova, Rep. of	228	248	3	5	0	0	8	15	89	55	0	4	15	18
Russian Federation	27 418	29 099	190	186	636	747	2 341	2 440	5 671	5 159	143	154	2 171	2 755
Turkey	18 493	23 596	837	718	42	104	1 805	2 035	1 359	1 704	299	501	2 301	2 835
Ukraine	5 020	4 895	11	32	145	158	190	233	823	781	9	12	707	490
European Free Trade Assoc.														
Iceland	575	864	14	20	0	16	114	139	18	23	14	20	19	51
Liechtenstein	46	52	0	0	0	0	2	3	8	10	0	0	12	7
Norway	7 543	10 070	184	210	32	80	1 451	1 676	374	407	127	178	501	757
Switzerland	19 131	25 308	325	299	285	493	4 190	4 884	1 676	1 951	350	508	1 326	1 658
Sub–Saharan Africa														
Angola	15	45	0	0	0	0	2	9	0	0	0	0	0	3
Benin	166	270	19	36	0	0	65	71	0	0	0	0	0	1
Botswana	162	210	12	4	0	0	37	55	16	8	2	0	7	4
Burkina Faso	193	272	14	15	0	0	57	64	3	2	0	0	4	12
Burundi	8	18	0	0	0	0	2	2	1	1	0	0	0	0
Cabo Verde	3	25	0	0	0	0	1	3	0	1	0	0	1	1
Cameroon	482	706	47	31	0	2	132	180	30	20	4	3	20	37
Central African Rep.	17	32	0	0	0	0	9	7	0	0	0	0	0	0
Chad	14	26	0	0	0	1	3	5	0	0	0	0	0	0
Comoros	3	0	0	0	0	0	1	0	0	0	0	0	0	0
Congo	69	111	4	3	0	0	27	31	2	2	0	0	0	1
Congo, Dem. Rep. of	38	114	0	2	0	0	15	29	0	2	0	0	0	2
Côte d'Ivoire	183	208	6	10	0	1	55	60	12	9	0	0	1	3
Djibouti	2	15	0	0	0	0	1	1	1	2	0	0	0	0
Equatorial Guinea	2	4	0	0	0	0	0	1	0	0	0	0	0	0
Eritrea	15	22	2	2	0	0	3	5	0	2	0	0	0	1
Ethiopia	402	865	56	63	0	3	77	147	3	20	1	0	4	19
Gabon	82	137	0	2	0	0	45	49	0	0	0	0	1	3
Gambia	95	124	1	0	0	0	42	46	0	0	0	0	1	0
Ghana	293	579	31	45	0	0	92	91	6	15	0	3	7	20
Guinea	16	49	0	2	0	0	5	12	1	0	0	0	0	2
Guinea–Bissau	20	37	0	0	0	0	9	14	0	0	0	0	0	0
Kenya	855	1 374	91	85	0	0	351	403	6	9	0	4	8	22
Lesotho	12	16	1	3	0	0	1	2	1	0	1	0	0	3
Liberia	6	11	1	0	0	0	2	5	0	0	0	0	1	1
Madagascar	152	188	6	9	0	0	69	56	3	3	0	0	2	3
Malawi	218	322	8	9	0	0	54	91	0	0	0	0	0	3
Mali	93	141	6	15	0	0	37	36	1	2	0	0	0	4
Mauritius	44	89	0	4	0	0	9	30	4	7	0	2	5	2
Mozambique	84	158	3	4	0	0	20	29	1	3	0	0	0	1
Namibia	64	139	0	0	12	10	21	35	0	3	0	0	1	5
Niger	81	108	9	16	0	0	17	22	1	4	0	1	1	0
Nigeria	1 977	1 961	265	144	9	41	271	305	45	102	2	6	87	146
Rwanda	34	143	1	7	0	0	10	30	0	1	0	1	0	2
Sao Tome and Principe	1	3	0	0	0	0	1	2	0	0	0	0	0	0
Senegal	228	338	14	18	0	0	59	76	11	11	1	3	7	5
Seychelles	21	34	0	1	0	0	5	11	0	0	0	0	0	0
Sierra Leone	12	45	0	0	0	0	6	5	0	0	0	0	0	0
Somalia	1	7	0	0	0	0	1	1	0	0	0	0	0	0
South Africa	5 611	9 309	187	302	110	328	1 745	2 187	394	748	48	47	362	641
South Sudan	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Swaziland	21	25	3	1	0	0	6	10	2	2	0	0	0	0
Tanzania	426	770	26	28	0	1	131	172	0	12	0	0	11	22
Togo	44	61	4	5	0	0	10	19	1	2	0	0	4	4
Uganda	403	757	16	21	0	1	148	216	2	3	0	3	4	11
Zambia	134	245	4	10	0	0	46	72	0	1	0	0	1	3
Zimbabwe	217	310	27	35	0	0	64	98	0	2	0	1	3	2
Arab States														
Algeria	1 339	2 302	23	50	4	28	104	168	189	250	42	85	332	596
Bahrain	114	155	2	0	0	1	16	16	3	5	2	6	16	28
Egypt	4 147	8 428	121	254	12	49	579	1 351	874	1 246	75	120	545	1 107
Iraq	195	841	8	19	0	4	12	57	22	85	0	22	19	171
Jordan	989	1 093	66	53	2	5	101	117	116	82	36	50	165	129
Kuwait	659	604	7	6	1	2	84	77	54	40	19	35	110	99
Lebanon	621	1 009	9	24	2	3	94	136	37	63	20	35	62	118
Libya	126	181	0	5	0	0	15	21	19	20	1	2	22	28
Mauritania	14	23	0	0	0	0	3	4	6	0	0	0	0	1
Morocco	1 214	1 574	37	55	6	3	123	147	158	158	16	28	114	166
Oman	327	591	10	15	2	5	38	84	23	59	9	6	53	99
Palestine	65	14	1	0	0	0	9	0	13	1	2	0	6	5
Qatar	217	1 242	0	6	1	14	34	185	11	91	4	54	32	227
Saudi Arabia	1 910	10 898	25	152	2	79	208	1 364	176	1 573	39	356	235	1 469
Sudan	150	309	20	18	1	1	40	55	4	28	2	3	6	13
Syrian Arab Rep.	218	229	39	18	0	0	52	36	12	15	0	0	20	18

Publications by field of science															
Geosciences		Mathematics		Medical sciences		Other life sciences		Physics		Psychology		Social sciences		Unclassified articles	
2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
20	26	65	69	17	38	1	3	105	222	1	0	3	2	34	56
451	1 245	491	1 004	1 596	2 355	34	90	1 106	2 336	12	36	21	59	1 841	5 444
405	473	635	630	2 697	2 918	47	52	1 540	1 280	122	106	91	76	728	1 469
3	6	8	9	8	25	0	1	73	63	0	0	0	1	21	46
2 612	3 015	1 524	1 573	1 773	1 352	9	8	7 977	7 941	14	31	21	34	2 336	3 704
1 229	1 341	508	933	6 248	6 852	107	134	1 028	1 648	17	32	79	103	2 634	4 656
172	205	379	334	144	205	0	4	1 476	1 510	1	1	2	8	961	922
140	173	18	6	134	191	14	21	38	54	5	9	4	5	43	136
1	0	0	0	15	13	0	0	5	9	0	0	0	0	3	10
1 267	1 576	198	270	2 198	2 593	128	162	497	579	82	102	90	129	414	1 351
1 345	1 830	391	527	5 444	6 603	87	123	2 498	2 736	156	188	120	163	938	3 345
1	9	0	0	6	9	1	0	0	0	0	1	0	1	5	13
11	24	3	2	25	47	0	0	11	23	0	0	1	0	31	66
29	23	5	19	15	42	5	4	7	5	2	1	3	4	22	41
5	14	1	4	63	67	0	0	3	6	0	0	1	4	42	84
2	7	0	0	2	1	0	1	0	0	0	0	1	0	0	6
0	13	0	3	0	1	0	0	0	0	0	0	0	1	1	2
40	54	11	26	60	98	1	1	58	56	0	0	4	10	75	188
2	2	0	0	4	8	0	0	0	0	1	0	0	0	1	15
3	1	0	0	5	6	0	0	0	1	0	0	1	1	2	11
0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
3	9	3	1	22	36	0	0	0	1	1	0	0	4	7	23
2	10	0	0	18	35	1	0	0	0	0	0	0	2	2	32
17	20	11	5	38	45	0	0	4	1	1	1	0	0	38	53
0	5	0	0	0	3	0	0	0	1	0	0	0	0	0	3
0	2	0	0	1	0	0	0	0	0	0	0	0	0	1	1
1	4	1	0	3	3	0	0	1	0	0	0	0	1	4	4
53	98	8	3	105	198	1	3	15	15	0	3	12	23	67	270
4	11	1	1	21	30	0	0	1	1	2	1	1	0	6	39
0	1	0	0	29	39	0	0	0	0	0	0	2	3	20	35
34	56	3	3	64	157	2	7	2	7	0	1	8	20	44	154
0	1	0	1	4	18	0	0	0	0	0	0	1	1	5	12
0	1	0	0	9	12	0	0	0	0	0	0	0	0	2	10
42	101	1	3	183	306	6	10	5	11	6	9	27	39	129	372
2	1	0	1	2	2	0	0	1	0	0	0	0	0	3	4
0	0	0	0	1	4	0	0	1	0	0	0	0	0	0	1
9	26	7	1	34	25	0	0	3	0	3	4	1	1	15	60
9	9	0	1	61	118	4	4	1	2	1	0	6	6	74	79
4	7	0	0	19	43	0	2	1	0	0	0	0	0	25	32
6	14	6	1	4	7	2	1	2	4	0	0	0	1	6	16
16	22	1	1	33	48	0	1	0	1	0	0	4	2	6	46
20	26	0	3	3	26	1	1	3	3	0	0	0	0	3	27
16	12	2	2	18	18	0	1	1	1	0	0	0	1	16	30
112	160	29	34	380	377	8	12	26	52	1	6	11	25	731	551
5	8	0	1	12	49	0	3	0	2	0	1	0	1	6	37
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
26	28	11	17	56	78	0	2	8	10	0	2	3	6	32	82
8	8	0	0	3	3	0	0	0	0	0	0	0	0	5	11
2	0	0	0	2	23	0	1	0	0	1	0	0	3	1	13
0	0	0	0	0	4	0	1	0	0	0	0	0	0	0	1
576	872	202	355	1 073	1 475	60	58	332	625	39	51	87	126	396	1 494
0	0	0	0	2	0	0	0	0	0	0	0	0	0	3	0
1	0	0	2	3	2	1	0	0	1	0	0	0	0	5	7
40	62	0	0	140	237	6	4	2	6	3	5	12	19	55	202
1	3	2	1	16	6	0	0	1	1	0	1	0	2	5	17
18	32	2	3	127	234	8	5	1	2	3	4	9	19	65	203
6	12	0	0	54	83	1	6	2	1	0	2	5	9	15	46
27	26	2	2	48	57	1	1	3	1	0	1	6	5	36	79
79	184	120	162	41	71	1	1	262	374	0	0	2	8	140	325
7	7	5	4	22	36	1	1	14	19	0	3	1	3	25	26
212	443	138	222	721	1 453	5	11	456	680	2	3	5	9	402	1 480
15	68	5	17	50	73	0	1	17	78	0	1	0	3	47	242
75	71	57	55	145	202	19	56	82	77	1	1	9	7	115	188
30	33	28	34	130	124	4	3	22	29	1	2	2	5	167	115
37	62	17	29	247	322	6	13	38	59	0	3	6	8	46	134
11	16	1	4	13	34	0	0	8	14	0	0	0	0	36	37
3	7	1	1	0	5	0	0	0	1	0	0	0	0	1	4
133	148	120	121	240	227	1	1	143	287	2	5	3	5	118	223
39	67	18	17	50	95	0	7	38	37	0	1	3	0	44	99
2	1	3	0	9	2	0	0	9	3	2	0	0	0	9	2
3	26	9	30	59	222	0	13	33	167	0	0	0	12	31	195
65	484	149	792	463	1 229	8	22	147	942	0	9	4	26	389	2 401
4	14	1	2	46	67	0	2	5	9	0	0	0	3	21	94
15	24	5	3	31	48	0	1	13	26	0	0	3	1	28	39

Table S9: Publications by major field of science, 2008 and 2014

	Publications by field of science													
	Total		Agricultural sciences		Astronomy		Biological sciences		Chemistry		Computer sciences		Engineering	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
Tunisia	2 068	3 068	91	167	3	10	429	514	194	302	39	95	281	455
United Arab Emirates	713	1 450	15	13	1	15	125	173	35	120	35	87	126	367
Yemen	64	202	0	2	0	2	7	19	7	25	0	3	5	17
Central Asia														
Kazakhstan	221	600	5	7	4	10	20	44	66	80	1	4	22	78
Kyrgyzstan	54	82	0	3	0	0	7	13	2	4	0	0	5	1
Mongolia	126	203	1	4	0	1	34	51	7	6	0	0	3	9
Tajikistan	49	46	0	1	4	2	5	4	13	6	0	0	3	3
Turkmenistan	3	24	0	0	0	0	0	1	0	0	0	0	0	2
Uzbekistan	306	323	8	8	11	10	28	27	60	49	0	1	22	30
South Asia														
Afghanistan	23	44	0	0	0	0	5	4	0	4	0	0	0	0
Bangladesh	797	1 394	40	82	1	19	196	255	65	84	16	27	70	143
Bhutan	8	36	1	1	0	0	3	10	0	1	0	0	1	0
India	37 228	53 733	1 711	1 604	327	590	5 891	7 529	6 628	9 437	492	1 041	4 875	7 827
Maldives	4	16	0	0	0	0	0	5	0	0	0	0	0	0
Nepal	253	455	6	19	3	0	55	86	2	15	0	0	5	19
Pakistan	3 089	6 778	143	253	4	74	632	1 120	511	438	32	202	240	645
Sri Lanka	430	599	39	44	0	3	70	90	20	29	2	2	26	29
South–East Asia														
Brunei Darussalam	43	106	0	0	0	0	8	18	1	10	1	2	1	13
Cambodia	86	206	4	7	0	0	25	55	3	1	0	0	1	1
China	102 368	256 834	1 795	4 510	581	1 298	12 870	30 991	21 536	34 956	1 997	7 759	15 109	41 835
China, Hong Kong SAR	7 660	852	51	9	21	5	867	75	631	67	524	74	1 360	185
China, Macao SAR	121	46	2	0	1	1	20	5	5	4	14	7	25	12
Indonesia	709	1 476	37	82	2	2	194	295	56	90	9	15	63	191
Japan	76 244	73 128	1 853	1 438	783	919	14 884	11 792	9 949	8 762	787	882	8 104	6 766
Korea, DPR	36	23	1	0	1	0	5	2	3	1	2	1	10	0
Korea, Rep. of	33 431	50 258	905	1 289	188	339	4 896	6 519	4 137	5 242	812	1 580	6 663	9 624
Lao PDR	58	129	6	11	0	0	14	29	1	1	0	0	1	2
Malaysia	2 852	9 998	120	324	1	7	316	914	582	945	71	391	484	2 231
Myanmar	39	70	3	1	0	0	13	18	1	0	0	0	0	3
Philippines	663	913	99	79	0	0	169	186	24	41	1	3	14	54
Singapore	7 075	10 553	33	62	1	3	981	1 482	859	1 332	344	527	1 541	1 752
Thailand	4 335	6 343	299	299	10	27	1 023	1 247	499	556	44	77	529	714
Timor–Leste	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Viet Nam	943	2 298	48	70	2	12	170	324	41	174	5	100	71	289
Oceania														
Australia	30 922	46 639	1 054	1 224	500	902	7 070	8 683	1 859	2 527	514	952	2 209	4 077
New Zealand	5 681	7 375	400	476	21	64	1 547	1 750	299	308	86	101	318	449
Cook Islands	0	7	0	0	0	0	0	1	0	0	0	0	0	0
Fiji	65	106	4	1	0	0	16	14	7	6	2	6	7	17
Kiribati	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Marshall Islands	1	5	0	1	0	0	0	0	0	0	0	0	0	0
Micronesia	3	12	0	1	0	0	3	4	0	0	0	0	0	0
Nauru	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Niue	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Palau	4	12	1	0	0	0	0	3	0	0	0	0	0	1
Papua New Guinea	78	110	4	1	0	0	46	43	0	2	0	0	0	2
Samoa	1	4	0	1	0	0	0	1	0	0	0	0	0	0
Solomon Islands	4	17	0	0	0	0	1	2	0	0	0	0	0	0
Tonga	4	6	0	1	0	0	0	1	0	0	0	0	0	0
Tuvalu	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Vanuatu	9	19	3	1	0	0	3	3	0	0	0	0	0	0

Source: data from Thomson Reuters' Web of Science, Science Citation Index Expanded, compiled for UNESCO by Science–Metrix, May 2015

	Publications by field of science															
	Geosciences		Mathematics		Medical sciences		Other life sciences		Physics		Psychology		Social sciences		Unclassified articles	
	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014	2008	2014
	137	296	131	184	381	292	0	1	175	311	3	4	5	22	199	415
	50	74	28	50	165	239	0	9	43	90	0	4	4	9	86	200
	5	14	3	6	9	29	0	0	8	25	0	0	0	1	20	59
	21	39	16	54	8	41	0	2	30	122	0	5	1	4	27	110
	17	23	1	3	8	6	0	0	9	11	0	0	0	0	5	18
	33	37	1	9	14	21	1	0	17	25	0	1	1	4	14	35
	1	5	4	8	3	2	0	0	9	7	0	0	0	0	7	8
	1	3	1	14	0	1	0	0	1	0	0	0	0	0	0	3
	6	11	19	41	15	12	0	0	110	105	0	1	1	0	26	28
	1	1	0	0	11	20	3	1	0	0	0	0	1	1	2	13
	87	82	8	20	115	201	3	0	77	107	1	3	13	12	105	359
	1	7	0	0	1	8	0	0	0	2	0	0	1	0	0	7
	1 759	2 777	886	1 040	4 805	5 442	32	40	4 910	6 338	22	52	77	107	4 813	9 909
	3	6	0	0	0	4	0	0	1	0	0	0	0	0	0	1
	28	55	1	1	65	106	0	4	2	12	0	0	5	8	81	130
	107	282	103	248	322	496	4	8	361	660	1	2	5	37	624	2 313
	43	56	2	2	100	109	4	3	13	86	1	2	4	8	106	136
	4	12	2	5	9	18	0	0	2	3	0	0	0	1	15	24
	16	19	0	0	27	45	0	3	0	1	0	0	1	6	9	68
	5 378	14 266	4 649	9 188	8 700	29 295	70	426	18 011	27 681	75	394	185	616	11 412	53 619
	506	37	396	49	1 548	161	88	9	1 081	79	44	6	46	9	497	87
	8	1	6	2	11	7	6	0	11	1	1	0	2	1	9	5
	114	180	14	16	102	164	1	10	39	62	3	13	10	19	65	337
	3 644	3 514	1 560	1 565	17 478	17 360	122	120	12 553	9 287	226	208	158	165	4 143	10 350
	2	1	0	2	3	3	0	0	4	5	0	0	0	0	5	8
	1 065	1 659	863	1 145	5 702	9 359	196	297	5 360	5 231	43	90	60	155	2 541	7 729
	2	19	0	1	22	25	0	0	2	0	0	0	0	3	10	38
	156	524	52	149	326	849	8	21	181	654	5	18	12	51	538	2 920
	4	9	0	0	13	18	0	0	0	2	0	0	1	2	4	17
	82	110	10	6	120	140	3	0	30	53	1	4	8	19	102	218
	158	354	203	251	1 032	1 518	18	73	1 272	1 210	21	46	33	57	579	1 886
	215	278	53	167	853	1 174	42	36	243	377	10	7	24	34	491	1 350
	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	82	195	131	257	120	174	1	5	184	306	1	2	11	9	76	381
	2 928	4 215	722	839	8 859	12 218	674	1 006	2 127	2 342	383	589	335	543	1 688	6 522
	704	896	148	175	1 396	1 661	82	100	268	302	88	97	81	93	243	903
	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	16	3	1	9	15	1	0	0	0	0	0	1	12	7	18
	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	0	3	0	0	0	1	0	0	0	0	0	0	0	1	0	2
	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	2	7	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	1	10	0	0	16	26	0	0	0	0	0	0	0	1	11	25
	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1
	0	3	0	0	3	8	0	0	0	0	0	0	0	0	0	4
	0	2	0	0	3	0	0	0	0	0	0	0	0	0	1	2
	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	4	0	0	2	6	0	0	0	0	0	0	0	1	0	4

Table S10: Scientific publications in international collaboration, 2008-2014

	Total number of publications	Number of publications with international co-authors	Publications with international co-authors (%)	Average citation rate	Percentage of papers in 10% most-cited papers
	2008–2014	2008–2014	2008–2014	2008–2012	2008–2012
North America					
Canada	357 500	180 314	50.4	1.25	13.1
United States of America	2 151 180	749 287	34.8	1.32	14.7
Latin America					
Argentina	51 685	23 847	46.1	0.93	7.1
Belize	86	77	89.5	1.20	14.6
Bolivia	1 309	1 230	94.0	1.40	11.6
Brazil	232 381	65 925	28.4	0.74	5.8
Chile	34 624	21 220	61.3	0.96	9.0
Colombia	18 558	11 308	60.9	0.99	9.0
Costa Rica	2 821	2 300	81.5	1.15	13.2
Ecuador	2 529	2 280	90.2	1.15	12.1
El Salvador	232	219	94.4	1.19	14.4
Guatemala	650	598	92.0	0.95	8.8
Guyana	121	89	73.6	0.90	3.1
Honduras	289	282	97.6	0.97	6.1
Mexico	68 383	30 721	44.9	0.82	6.4
Nicaragua	400	386	96.5	1.04	12.2
Panama	2 074	1 932	93.2	1.56	16.6
Paraguay	372	338	90.9	0.99	8.7
Peru	4 339	3 916	90.3	1.29	12.5
Suriname	81	68	84.0	0.77	7.5
Uruguay	4 728	3 330	70.4	1.09	9.8
Venezuela	7 450	4 183	56.1	0.69	5.6
Caribbean					
Antigua and Barbuda	21	20	95.2	–	–
Bahamas	132	119	90.2	1.01	6.6
Barbados	380	297	78.2	0.93	9.8
Cuba	5 481	3 964	72.3	0.67	5.5
Dominica	57	53	93.0	–	–
Dominican Rep.	308	292	94.8	0.97	9.6
Grenada	701	654	93.3	0.64	4.4
Haiti	257	251	97.7	1.62	14.8
Jamaica	1 108	557	50.3	0.48	4.0
St Kitts and Nevis	102	92	90.2	1.05	11.3
St Lucia	15	14	93.3	–	–
St Vincent and the Grenadines	12	11	91.7	–	–
Trinidad and Tobago	1 073	661	61.6	0.61	5.6
European Union					
Austria	81 174	53 248	65.6	1.30	14.0
Belgium	115 353	74 806	64.8	1.39	15.3
Bulgaria	15 476	8 480	54.8	0.91	7.1
Croatia	20 248	8 861	43.8	0.83	7.0
Cyprus	4 540	3 453	76.1	1.28	13.5
Czech Rep.	64 149	32 788	51.1	0.97	8.8
Denmark	85 311	52 635	61.7	1.50	16.6
Estonia	8 852	5 381	60.8	1.26	13.0
Finland	67 217	38 945	57.9	1.27	12.7
France	438 755	238 170	54.3	1.20	12.7
Germany	608 713	320 067	52.6	1.24	13.5
Greece	69 089	31 843	46.1	1.06	10.3
Hungary	39 242	22 322	56.9	1.01	9.4
Ireland	42 916	25 368	59.1	1.34	14.3
Italy	366 894	168 632	46.0	1.17	12.0
Latvia	3 482	1 942	55.8	0.74	6.7
Lithuania	12 329	4 676	37.9	0.75	5.8
Luxembourg	4 013	3 330	83.0	1.24	13.3
Malta	1 003	665	66.3	1.00	11.8
Netherlands	202 703	118 246	58.3	1.48	16.8
Poland	144 090	49 019	34.0	0.72	5.7
Portugal	69 026	37 997	55.0	1.12	11.2
Romania	45 236	17 192	38.0	0.81	7.5
Slovakia	19 974	11 493	57.5	0.83	7.0
Slovenia	21 836	10 979	50.3	1.04	9.4
Spain	309 076	147 698	47.8	1.16	11.8
Sweden	136 603	84 276	61.7	1.34	14.1
United Kingdom	582 678	325 807	55.9	1.36	15.1

	Main foreign collaborators (2008–2014)				
	First collaborator	Second collaborator	Third collaborator	Fourth collaborator	Fifth collaborator
	United States of America (85 069)	United Kingdom (25 879)	China (19 522)	Germany (19 244)	France (18 956)
	China (119 594)	United Kingdom (100 537)	Germany (94 322)	Canada (85 069)	France (62 636)
	United States of America (8 000)	Spain (5 246)	Brazil (4 237)	Germany (3 285)	France (3 093)
	United States of America (60)	United Kingdom (20)	Canada (9)	Mexico (8)	Australia (7); France (7)
	United States of America (425)	Brazil (193)	France (192)	Spain (187)	United Kingdom (144)
	United States of America (24 964)	France (8 938)	United Kingdom (8 784)	Germany (8 054)	Spain (7 268)
	United States of America (7 850)	Spain (4 475)	Germany (3 879)	France (3 562)	United Kingdom (3 443)
	United States of America (4 386)	Spain (3 220)	Brazil (2 555)	United Kingdom (1 943)	France (1 854)
	United States of America (1 169)	Spain (365)	Brazil (295)	Mexico (272)	France (260)
	United States of America (1 070)	Spain (492)	Brazil (490)	United Kingdom (475)	France (468)
	United States of America (108)	Mexico (45)	Spain (38)	Guatemala (34); Honduras (34)	
	United States of America (388)	Mexico (116)	Brazil (74)	United Kingdom (63)	Costa Rica (54)
	United States of America (45)	Canada (20)	United Kingdom (13)	France (12)	Netherlands (8)
	United States of America (179)	Mexico (58)	Brazil (42)	Argentina (41)	Colombia (40)
	United States of America (12 873)	Spain (6 793)	France (3 818)	United Kingdom (3 525)	Germany (3 345)
	United States of America (157)	Sweden (86)	Mexico (52)	Costa Rica (51)	Spain (48)
	United States of America (1 155)	Germany (311)	United Kingdom (241)	Canada (195)	Brazil (188)
	United States of America (142)	Brazil (113)	Argentina (88)	Spain (62)	Uruguay (36); Peru (36)
	United States of America (2 035)	Brazil (719)	United Kingdom (646)	Spain (593)	France (527)
	Netherlands (38)	United States of America (16)	Canada (8)	Brazil (6)	Germany (5); France (5); Ecuador (5)
	United States of America (854)	Brazil (740)	Argentina (722)	Spain (630)	France (365)
	United States of America (1 417)	Spain (1093)	France (525)	Mexico (519)	Brazil (506)
	United States of America (11)	St Vincent and the Grenadines (4); France (4)		United Kingdom (3); St Kitts and Nevis (3); Barbados (3)	
	United States of America (97)	Canada (37)	United Kingdom (34)	Germany (8)	Australia (6)
	United States of America (139)	United Kingdom (118)	Canada (86)	Germany (48)	Belgium (43); Japan (43)
	Spain (1 235)	Mexico (806)	Brazil (771)	United States of America (412)	Germany (392)
	United States of America (29)	Canada (7)	United Kingdom (6); Trinidad and Tobago (6); Hungary (6)		
	United States of America (168)	United Kingdom (52)	Mexico (49)	Spain (45)	Brazil (38)
	United States of America (532)	Iran, Islamic Rep. of (91)	United Kingdom (77)	Poland (63)	Turkey (46)
	United States of America (208)	France (38)	United Kingdom (18)	South Africa (14)	Canada (13)
	United States of America (282)	United Kingdom (116)	Canada (77)	Trinidad and Tobago (43)	South Africa (28)
	United States of America (46)	Canada (17)	South Africa (12)	United Kingdom (10)	China (8)
	South Africa (4)	United States of America (3)	St Kitts and Nevis (2); Costa Rica (2); Antigua and Barbuda (2); Barbados (2); United Kingdom (2); Canada (2)		
	United States of America (6)	Barbados (4); Antigua and Barbuda (4)		Trinidad and Tobago (3); St Kitts and Nevis (3)	
	United States of America (251)	United Kingdom (183)	Canada (95)	India (63)	Jamaica (43)
	Germany (21 483)	United States of America (13 783)	United Kingdom (8 978)	Italy (7 678)	France (7 425)
	United States of America (18 047)	France (17 743)	United Kingdom (15 109)	Germany (14 718)	Netherlands (14 307)
	Germany (2 632)	United States of America (1 614)	Italy (1 566)	France (1 505)	United Kingdom (1 396)
	Germany (2 383)	United States of America (2 349)	Italy (1 900)	United Kingdom (1 771)	France (1 573)
	Greece (1 426)	United States of America (1 170)	United Kingdom (1 065)	Germany (829)	Italy (776)
	Germany (8 265)	United States of America (7 908)	France (5 884)	United Kingdom (5 775)	Italy (4 456)
	United States of America (15 933)	United Kingdom (12 176)	Germany (11 359)	Sweden (8 906)	France (6 978)
	Finland (1 488)	United Kingdom (1 390)	Germany (1 368)	United States of America (1 336)	Sweden (1 065)
	United States of America (10 756)	United Kingdom (8 507)	Germany (8 167)	Sweden (7 244)	France (5 109)
	United States of America (62 636)	Germany (42 178)	United Kingdom (40 595)	Italy (32 099)	Spain (25 977)
	United States of America (94 322)	United Kingdom (54 779)	France (42 178)	Switzerland (34 164)	Italy (33 279)
	United States of America (10 374)	United Kingdom (8 905)	Germany (7 438)	Italy (6 184)	France (5 861)
	United States of America (6 367)	Germany (6 099)	United Kingdom (4 312)	France (3 740)	Italy (3 588)
	United Kingdom (9 735)	United States of America (7 426)	Germany (4 580)	France (3 541)	Italy (2 751)
	United States of America (53 913)	United Kingdom (34 639)	Germany (33 279)	France (32 099)	Spain (24 571)
	Germany (500)	United States of America (301)	Lithuania (298)	Russian Federation (292)	United Kingdom (289)
	Germany (1 214)	United States of America (1 065)	United Kingdom (982)	France (950)	Poland (927)
	France (969)	Germany (870)	Belgium (495)	United Kingdom (488)	United States of America (470)
	United Kingdom (318)	Italy (197)	France (126)	Germany (120)	United States of America (109)
	United States of America (36 295)	Germany (29 922)	United Kingdom (29 606)	France (17 549)	Italy (15 190)
	United States of America (13 207)	Germany (12 591)	United Kingdom (8 872)	France (8 795)	Italy (6 944)
	Spain (10 019)	United States of America (8 107)	United Kingdom (7 524)	France (6 054)	Germany (5 798)
	France (4 424)	Germany (3 876)	United States of America (3 533)	Italy (3 268)	United Kingdom (2 530)
	Czech Rep. (3 732)	Germany (2 719)	United States of America (2 249)	United Kingdom (1 750)	France (1 744)
	United States of America (2 479)	Germany (2 315)	Italy (2 195)	United Kingdom (1 889)	France (1 666)
	United States of America (39 380)	United Kingdom (28 979)	Germany (26 056)	France (25 977)	Italy (24 571)
	United States of America (24 023)	United Kingdom (17 928)	Germany (16 731)	France (10 561)	Italy (9 371)
	United States of America (100 537)	Germany (54 779)	France (40 595)	Italy (34 639)	Netherlands (29 606)

Table S10: Scientific publications in international collaboration, 2008-2014

	Total number of publications	Number of publications with international co-authors	Publications with international co-authors (%)	Average citation rate	Percentage of papers in 10% most-cited papers
	2008–2014	2008–2014	2008–2014	2008–2012	2008–2012
South–East Europe					
Albania	782	471	60.2	0.56	4.0
Bosnia and Herzegovina	2 304	1 397	60.6	0.73	6.4
Macedonia, FYR	1 795	1 198	66.7	0.80	6.7
Montenegro	995	731	73.5	0.71	5.8
Serbia	28 782	10 635	37.0	0.89	7.5
Other Europe and West Asia					
Armenia	4 472	2 688	60.1	1.03	9.2
Azerbaijan	3 013	1 598	53.0	0.73	5.6
Belarus	7 318	4 274	58.4	0.79	6.6
Georgia	3 174	2 283	71.9	1.29	10.7
Iran, Islamic Rep. of	137 557	29 366	21.3	0.81	7.4
Israel	75 268	37 142	49.3	1.19	11.9
Moldova, Rep. of	1 691	1 204	71.2	0.77	7.9
Russian Federation	194 364	64 190	33.0	0.52	3.8
Turkey	152 333	28 643	18.8	0.71	5.8
Ukraine	33 154	15 761	47.5	0.59	4.4
European Free Trade Assoc.					
Iceland	5 207	4 029	77.4	1.71	18.3
Liechtenstein	333	302	90.7	1.12	12.3
Norway	62 947	38 581	61.3	1.29	13.4
Switzerland	157 286	108 371	68.9	1.56	18.0
Sub–Saharan Africa					
Angola	225	217	96.4	0.67	6.3
Benin	1 506	1 320	87.6	0.82	6.8
Botswana	1 121	894	79.8	1.14	7.6
Burkina Faso	1 704	1 557	91.4	0.96	8.0
Burundi	107	103	96.3	0.70	10.2
Cabo Verde	85	85	100.0	1.45	18.4
Cameroon	4 030	3 257	80.8	0.71	4.9
Central African Rep.	176	166	94.3	0.84	8.7
Chad	116	110	94.8	0.72	5.1
Comoros	18	18	100.0	–	–
Congo	608	555	91.3	0.90	8.2
Congo, Dem. Rep. of	675	628	93.0	1.00	10.3
Côte d'Ivoire	1 445	1 056	73.1	0.71	7.2
Djibouti	51	45	88.2	–	–
Equatorial Guinea	27	27	100.0	–	–
Eritrea	100	92	92.0	0.71	10.6
Ethiopia	4 323	3 069	71.0	0.82	6.3
Gabon	717	679	94.7	0.98	9.0
Gambia	687	655	95.3	1.24	15.4
Ghana	3 076	2 401	78.1	1.08	8.8
Guinea	198	193	97.5	0.96	7.6
Guinea–Bissau	172	172	100.0	1.09	14.9
Kenya	7 727	6 705	86.8	1.19	11.3
Lesotho	135	123	91.1	0.72	6.7
Liberia	56	56	100.0	–	–
Madagascar	1 234	1 136	92.1	0.89	8.8
Malawi	1 855	1 672	90.1	1.38	13.1
Mali	933	891	95.5	1.17	12.0
Mauritius	488	337	69.1	0.73	5.9
Mozambique	865	834	96.4	1.86	12.6
Namibia	646	583	90.2	0.93	10.0
Niger	598	560	93.6	0.93	9.3
Nigeria	13 780	5 109	37.1	0.60	4.1
Rwanda	590	562	95.3	1.05	9.0
Sao Tome and Principe	11	11	100.0	–	–
Senegal	2 135	1 841	86.2	0.85	8.1
Seychelles	198	190	96.0	0.99	8.1
Sierra Leone	178	171	96.1	0.85	9.1
Somalia	20	20	100.0	–	–
South Africa	52 166	29 473	56.5	1.04	9.8
South Sudan	53	52	98.1	–	–
Swaziland	238	205	86.1	0.91	9.7
Tanzania	4 018	3 588	89.3	1.17	13.0
Togo	363	302	83.2	0.52	2.8
Uganda	4 193	3 686	87.9	1.33	12.9
Zambia	1 316	1 263	96.0	1.25	12.6
Zimbabwe	1 638	1 356	82.8	1.21	11.9

Main foreign collaborators (2008–2014)				
First collaborator	Second collaborator	Third collaborator	Fourth collaborator	Fifth collaborator
Italy (144)	Germany (68)	Greece (61)	France (52)	Serbia (46)
Serbia (555)	Croatia (383)	Slovenia (182)	Germany (165)	United States of America (141)
Serbia (243)	Germany (215)	United States of America (204)	Bulgaria (178)	Italy (151)
Serbia (411)	Italy (92)	Germany (91)	France (86)	Russian Federation (81)
Germany (2 240)	United States of America (2 149)	Italy (1 892)	United Kingdom (1 825)	France (1 518)
United States of America (1 346)	Germany (1 333)	France (1 247); Russian Federation (1 247)		Italy (1 191)
Turkey (866)	Russian Federation (573)	United States of America (476)	Germany (459)	United Kingdom (413)
Russian Federation (2 059)	Germany (1 419)	Poland (1 204)	United States of America (1 064)	France (985)
United States of America (1 153)	Germany (1 046)	Russian Federation (956)	United Kingdom (924)	Italy (909)
United States of America (6 377)	Canada (3 433)	United Kingdom (3 318)	Germany (2 761)	Malaysia (2 402)
United States of America (19 506)	Germany (7 219)	United Kingdom (4 895)	France (4 422)	Italy (4 082)
Germany (276)	United States of America (235)	Russian Federation (214)	Romania (197)	France (153)
Germany (17 797)	United States of America (17 189)	France (10 475)	United Kingdom (8 575)	Italy (6 888)
United States of America (10 591)	Germany (4 580)	United Kingdom (4 036)	Italy (3 314)	France (3 009)
Russian Federation (3 943)	Germany (3 882)	United States of America (3 546)	Poland (3 072)	France (2 451)
United States of America (1 514)	United Kingdom (1 095)	Sweden (1 078)	Denmark (750)	Germany (703)
Austria (121)	Germany (107)	Switzerland (100)	United States of America (68)	France (19)
United States of America (10 774)	United Kingdom (8 854)	Sweden (7 540)	Germany (7 034)	France (5 418)
Germany (34 164)	United States of America (33 638)	United Kingdom (20 732)	France (19 832)	Italy (15 618)
Portugal (73)	United States of America (34)	Brazil (32)	United Kingdom (31)	Spain (26); France (26)
France (529)	Belgium (206)	United States of America (155)	United Kingdom (133)	Netherlands (125)
United States of America (367)	South Africa (241)	United Kingdom (139)	Canada (58)	Germany (51)
France (676)	United States of America (261)	United Kingdom (254)	Belgium (198)	Germany (156)
Belgium (38)	China (22)	United States of America (18)	Kenya (16)	United Kingdom (13)
Portugal (42)	Spain (23)	United Kingdom (15)	United States of America (11)	Germany (8)
France (1153)	United States of America (528)	Germany (429)	South Africa (340)	United Kingdom (339)
France (103)	United States of America (32)	Cameroon (30)	Gabon (29)	Senegal (23)
France (66)	Switzerland (28)	Cameroon (20)	United States of America (14); United Kingdom (14)	
France (7)	United Kingdom (4)	Morocco (3); Madagascar (3)		United States of America (2); Italy (2)
France (191)	United States of America (152)	Belgium (132)	United Kingdom (75)	Switzerland (68)
Belgium (286)	United States of America (189)	France (125)	United Kingdom (77)	Switzerland (65)
France (610)	United States of America (183)	Switzerland (162)	United Kingdom (109)	Burkina Faso (93)
France (31)	United States of America (6); United Kingdom (6)		Canada (5)	Spain (4)
United States of America (13)	Spain (11)	United Kingdom (10)	Cameroon (4); South Africa (4)	
United States of America (24)	India (20)	Italy (18)	Netherlands (13)	United Kingdom (11)
United States of America (776)	United Kingdom (538)	Germany (314)	India (306)	Belgium (280)
France (334)	Germany (231)	United States of America (142)	United Kingdom (113)	Netherlands (98)
United Kingdom (473)	United States of America (216)	Belgium (92)	Netherlands (69)	Kenya (67)
United States of America (830)	United Kingdom (636)	Germany (291)	South Africa (260)	Netherlands (256)
France (71)	United Kingdom (38)	United States of America (31)	China (27)	Senegal (26)
Denmark (112)	Sweden (50)	Gambia (40); United Kingdom (40)	–	United States of America (24)
United States of America (2 856)	United Kingdom (1 821)	South Africa (750)	Germany (665)	Netherlands (540)
South Africa (56)	United States of America (34)	United Kingdom (13)	Switzerland (10)	Australia (8)
United States of America (36)	United Kingdom (12)	France (11)	Ghana (6)	Canada (5)
France (530)	United States of America (401)	United Kingdom (180)	Germany (143)	South Africa (78)
United States of America (739)	United Kingdom (731)	South Africa (314)	Netherlands (129); Kenya (129)	
United States of America (358)	France (281)	United Kingdom (155)	Burkina Faso (120)	Senegal (97)
United Kingdom (101)	United States of America (80)	France (44)	India (43)	South Africa (40)
United States of America (239)	Spain (193)	South Africa (155)	United Kingdom (138)	Portugal (113)
South Africa (304)	United States of America (184)	Germany (177)	United Kingdom (161)	Australia (115)
France (238)	United States of America (145)	Nigeria (82)	United Kingdom (77)	Senegal (71)
United States of America (1 309)	South Africa (953)	United Kingdom (914)	Germany (434)	China (329)
United States of America (244)	Belgium (107)	Netherlands (86)	Kenya (83)	United Kingdom (82)
Portugal (5); United Kingdom (5)		United States of America (4)	Denmark (2); Angola (2)	
France (1 009)	United States of America (403)	United Kingdom (186)	Burkina Faso (154)	Belgium (139)
United Kingdom (69)	United States of America (64)	Switzerland (52)	France (41)	Australia (31)
United States of America (87)	United Kingdom (41)	Nigeria (20)	China (16); Germany (16)	
Kenya (9)	Egypt (8)	United Kingdom (6)	United States of America (5)	Switzerland (3)
United States of America (9 920)	United Kingdom (7 160)	Germany (4 089)	Australia (3 448)	France (3 445)
United States of America (33)	United Kingdom (22)	Uganda (16)	Kenya (8); Sudan (8)	
South Africa (104)	United States of America (59)	United Kingdom (45)	Tanzania (12); Switzerland (12)	
United States of America (1 212)	United Kingdom (1 129)	Kenya (398)	Switzerland (359)	South Africa (350)
France (146)	Benin (57)	United States of America (50)	Burkina Faso (47)	Côte d'Ivoire (31)
United States of America (1 709)	United Kingdom (1031)	Kenya (477)	South Africa (409)	Sweden (311)
United States of America (673)	United Kingdom (326)	South Africa (243)	Switzerland (101)	Kenya (100)
South Africa (526)	United States of America (395)	United Kingdom (371)	Netherlands (132)	Uganda (124)

Table S10: Scientific publications in international collaboration, 2008-2014

	Total number of publications	Number of publications with international co-authors	Publications with international co-authors (%)	Average citation rate	Percentage of papers in 10% most-cited papers
	2008–2014	2008–2014	2008–2014	2008–2012	2008–2012
Arab States					
Algeria	12 577	7 432	59.1	0.68	5.2
Bahrain	951	648	68.1	0.53	3.8
Egypt	44 239	22 568	51.0	0.77	6.5
Iraq	3 137	1 915	61.0	0.55	3.7
Jordan	7 226	3 747	51.9	0.80	5.9
Kuwait	4 330	2 115	48.8	0.73	6.1
Lebanon	5 409	3 583	66.2	0.85	7.9
Libya	1 017	810	79.6	0.65	4.7
Mauritania	138	133	96.4	0.87	7.5
Morocco	9 928	6 235	62.8	0.69	5.9
Oman	3 062	2 137	69.8	0.76	6.3
Palestine	414	232	56.0	0.54	3.8
Qatar	3 777	3 279	86.8	1.07	11.5
Saudi Arabia	40 534	29 271	72.2	1.09	10.8
Sudan	1 757	1 325	75.4	0.97	5.9
Syrian Arab Rep.	1 924	1 193	62.0	0.81	6.2
Tunisia	18 687	9 813	52.5	0.66	4.5
United Arab Emirates	7 323	5 272	72.0	0.85	7.7
Yemen	987	841	85.2	0.78	7.7
Central Asia					
Kazakhstan	2 442	1 496	61.3	0.51	4.5
Kyrgyzstan	471	373	79.2	0.67	6.2
Mongolia	1 189	1 134	95.4	0.73	6.2
Tajikistan	366	250	68.3	0.39	2.9
Turkmenistan	86	76	88.4	0.77	7.4
Uzbekistan	2 267	1 373	60.6	0.48	3.0
South Asia					
Afghanistan	226	218	96.5	0.74	9.7
Bangladesh	7 664	5 445	71.0	0.79	6.8
Bhutan	173	157	90.8	0.76	7.6
India	314 669	67 146	21.3	0.76	6.4
Maldives	48	47	97.9	–	–
Nepal	2 510	1 919	76.5	1.02	8.3
Pakistan	35 546	15 034	42.3	0.81	7.2
Sri Lanka	3 305	2 175	65.8	0.96	6.0
South–East Asia					
Brunei Darussalam	435	315	72.4	0.85	6.6
Cambodia	1 052	999	95.0	1.39	14.3
China	1 137 882	277 145	24.4	0.98	10.0
China, Hong Kong SAR	53 296	34 611	64.9	1.34	14.9
China, Macao SAR	1 593	1 264	79.3	1.24	12.4
Indonesia	7 821	6 712	85.8	0.96	8.4
Japan	523 744	142 163	27.1	0.88	7.8
Korea, DPR	199	175	87.9	0.65	3.1
Korea, Rep. of	298 768	82 513	27.6	0.89	7.9
Lao PDR	715	695	97.2	1.02	10.0
Malaysia	47 163	21 895	46.4	0.83	8.4
Myanmar	366	343	93.7	0.69	6.4
Philippines	5 558	3 864	69.5	1.15	12.1
Singapore	62 498	35 697	57.1	1.47	16.4
Thailand	38 627	19 058	49.3	0.95	8.2
Timor–Leste	17	16	94.1	–	–
Viet Nam	10 572	8 089	76.5	0.86	8.1
Oceania					
Australia	269 403	138 976	51.6	1.31	14.1
New Zealand	46 394	27 305	58.9	1.22	12.0
Cook Islands	22	22	100.0	–	–
Fiji	547	453	82.8	0.93	7.9
Kiribati	9	9	100.0	–	–
Marshall Islands	20	17	85.0	–	–
Micronesia	49	38	77.6	–	–

Main foreign collaborators (2008–2014)				
First collaborator	Second collaborator	Third collaborator	Fourth collaborator	Fifth collaborator
France (4 883)	Saudi Arabia (524)	Spain (440)	United States of America (383)	Italy (347)
Saudi Arabia (137)	Egypt (101)	United Kingdom (93)	United States of America (89)	Tunisia (75)
Saudi Arabia (7 803)	United States of America (4 725)	Germany (2 762)	United Kingdom (2 162)	Japan (1 755)
Malaysia (595)	United Kingdom (281)	United States of America (279)	China (133)	Germany (128)
United States of America (1 153)	Germany (586)	Saudi Arabia (490)	United Kingdom (450)	Canada (259)
United States of America (566)	Egypt (332)	United Kingdom (271)	Canada (198)	Saudi Arabia (185)
United States of America (1 307)	France (1 277)	Italy (412)	United Kingdom (337)	Canada (336)
United Kingdom (184)	Egypt (166)	India (99)	Malaysia (79)	France (78)
France (62)	Senegal (40)	United States of America (18)	Spain (16)	Tunisia (15)
France (3 465)	Spain (1 338)	United States of America (833)	Italy (777)	Germany (752)
United States of America (333)	United Kingdom (326)	India (309)	Germany (212)	Malaysia (200)
Egypt (50)	Germany (48)	United States of America (35)	Malaysia (26)	United Kingdom (23)
United States of America (1 168)	United Kingdom (586)	China (457)	France (397)	Germany (373)
Egypt (7 803)	United States of America (5 794)	United Kingdom (2 568)	China (2 469)	India (2 455)
Saudi Arabia (213)	Germany (193)	United Kingdom (191)	United States of America (185)	Malaysia (146)
France (193)	United Kingdom (179)	Germany (175)	United States of America (170)	Italy (92)
France (5 951)	Spain (833)	Italy (727)	Saudi Arabia (600)	United States of America (544)
United States of America (1505)	United Kingdom (697)	Canada (641)	Germany (389)	Egypt (370)
Malaysia (255)	Egypt (183)	Saudi Arabia (158)	United States of America (106)	Germany (72)
Russian Federation (565)	United States of America (329)	Germany (240)	United Kingdom (182)	Japan (150)
Russian Federation (99)	Turkey (74); Germany (74)		United States of America (56)	Kazakhstan (43)
Japan (301)	United States of America (247)	Russian Federation (242)	Germany (165)	Korea, Rep. of (142)
Pakistan (68)	Russian Federation (58)	United States of America (46)	Germany (26)	United Kingdom (20)
Turkey (50)	Russian Federation (11)	United States of America (6); Italy (6)		Germany (4); China (4)
Russian Federation (326)	Germany (258)	United States of America (198)	Italy (131)	Spain (101)
United States of America (97)	United Kingdom (52)	Pakistan (29)	Japan (26); Egypt (26)	
United States of America (1 394)	Japan (1 218)	United Kingdom (676)	Malaysia (626)	Korea, Rep. of (468)
United States of America (44)	Australia (40)	Thailand (37)	Japan (26)	India (18)
United States of America (21 684)	Germany (8 540)	United Kingdom (7 847)	Korea, Rep. of (6 477)	France (5 859)
India (14)	Italy (11)	United States of America (8)	Australia (6)	United Kingdom (5); Sweden (5); Japan (5)
United States of America (486)	India (411)	United Kingdom (272)	Japan (256)	Korea, Rep. of (181)
United States of America (3 074)	China (2 463)	United Kingdom (2 460)	Saudi Arabia (1 887)	Germany (1 684)
United Kingdom (548)	United States of America (516)	Australia (458)	India (332)	Japan (285)
Malaysia (68)	United Kingdom (47)	United States of America (46)	Australia (44)	Singapore (42)
United States of America (307)	Thailand (233)	France (230)	United Kingdom (188)	Japan (136)
United States of America (119 594)	Japan (26 053)	United Kingdom (25 151)	China, Hong Kong SAR (22 561)	Australia (21 058)
China (22 561)	United States of America (7 396)	Australia (2 768)	United Kingdom (2 675)	Canada (1 679)
China (809)	China, Hong Kong SAR (412)	United States of America (195)	United Kingdom (51)	Portugal (40)
Japan (1 848)	United States of America (1 147)	Australia (1 098)	Malaysia (950)	Netherlands (801)
United States of America (50 506)	China (26 053)	Germany (15 943)	United Kingdom (14 796)	Korea, Rep. of (12 108)
China (85)	Korea, Rep. of (41)	Germany (32)	United States of America (12)	Australia (9)
United States of America (42 004)	Japan (12 108)	China (11 993)	India (6 477)	Germany (6 341)
Thailand (191)	United Kingdom (161)	United States of America (136)	France (125)	Australia (117)
United Kingdom (3 076)	India (2 611)	Australia (2 425)	Iran, Islamic Rep. of (2 402)	United States of America (2 308)
Japan (102)	Thailand (91)	United States of America (75)	Australia (46)	United Kingdom (43)
United States of America (1 298)	Japan (909)	Australia (538)	China (500)	United Kingdom (410)
China (11 179)	United States of America (10 680)	Australia (4 166)	United Kingdom (4 055)	Japan (2 098)
United States of America (6 329)	Japan (4 108)	United Kingdom (2 749)	Australia (2 072)	China (1 668)
Australia (8)	Japan (3); Portugal (3); Czech Rep. (3)			China (2); United States of America (2)
United States of America (1 401)	Japan (1 384)	Korea, Rep. of (1 289)	France (1126)	United Kingdom (906)
United States of America (43 225)	United Kingdom (29 324)	China (21 058)	Germany (15 493)	Canada (12 964)
United States of America (8 853)	Australia (7 861)	United Kingdom (6 385)	Germany (3 021)	Canada (2 500)
United States of America (17)	Australia (11); New Zealand (11)		France (4)	Brazil (3); Japan (3)
Australia (229)	United States of America (110)	New Zealand (94)	United Kingdom (81)	India (66)
Australia (7)	New Zealand (6)	United States of America (5); Fiji (5)		Papua New Guinea (4)
United States of America (11)	Micronesia (6)	Fiji (5); Australia (5)		New Zealand (3); Palau (3); Papua New Guinea (3)
United States of America (26)	Australia (9)	Fiji (8)	Marshall Islands (6)	New Zealand (5); Palau (5)

Table S10: Scientific publications in international collaboration, 2008-2014

	Total number of publications	Number of publications with international co-authors	Publications with international co-authors (%)	Average citation rate	Percentage of papers in 10% most-cited papers
	2008–2014	2008–2014	2008–2014	2008–2012	2008–2012
Nauru	2	2	100.0	–	–
Niue	3	3	100.0	–	–
Palau	46	40	87.0	–	–
Papua New Guinea	646	583	90.2	0.88	9.0
Samoa	9	8	88.9	–	–
Solomon Islands	74	73	98.6	1.00	13.6
Tonga	24	24	100.0	–	–
Tuvalu	5	5	100.0	–	–
Vanuatu	114	108	94.7	0.81	3.3

Source: data from Thomson Reuters' Web of Science, Science Citation Index Expanded, compiled for UNESCO by Science–Metrix, May 2015

KEY TO ALL TABLES:

– : data unavailable
–n/+n: data refer to n years before or after reference year
0: magnitude nil or negligible
a: not applicable
b: overestimated or based on overestimated data
c: including other classes
d: including business enterprise
e: including higher education
f: including private non–profit
g: included elsewhere
h: excluding business enterprise
i: excluding government
j: excluding higher education
k: government only
l: higher education only
m: included in business
n: included in government
o: excluding most or all capital expenditures
p: excluding defence (all or mostly)
q: underestimated or partial data
r: estimation
s: break in series with previous year for which data are shown
t: the sum of the breakdown does not add to the total
u: based on R&D budget
v: provisional data

METHODOLOGICAL NOTE

Bibliographic data

Publication data have been compiled for UNESCO by Science–Metrix from Thomson Reuters' Web of Science, Science Citation Index Expanded, as of May 2015.

Economic data

Data on economic indicators, such as gross domestic product (GDP) and purchasing power parity (PPP), are based on the World Bank's economic data release of April 2015: http://data.worldbank.org/products/wdi.
(See the note on the cut–off date.)

It should be noted that, since 2014, the UNESCO Institute for Statistics has used data on total general government expenditure (all sectors) from the International Monetary Fund's *World Economic Outlook* database as the denominator for its indicator entitled Expenditure on education as a percentage of total government expenditure. For more information about the change in methodology, please visit: www.uis.unesco.org/education

	Main foreign collaborators (2008–2014)				
	First collaborator	Second collaborator	Third collaborator	Fourth collaborator	Fifth collaborator
	Australia (2)	Solomon Islands (1); Cook Islands (1); Micronesia (1); Vanuatu (1); France (1); Niue (1); Kiribati (1); Tonga (1); Palau (1); Iceland (1); Marshall Islands (1); Tuvalu (1); United States of America (1); New Zealand (1); Fiji (1); Papua New Guinea (1)			
	Australia (3); Micronesia (3)		France (2); Solomon Islands (2); Cook Islands (2); Papua New Guinea (2); Fiji (2); Palau (2); Vanuatu (2); Tonga (2); Kiribati (2); Tuvalu (2); New Zealand (2); United States of America (2); Iceland (2); Marshall Islands (2)		
	United States of America (27)	Australia (20)	Japan (5); Micronesia (5)		Papua New Guinea (3); Fiji (3); Marshall Islands (3); Philippines (3)
	Australia (375)	United States of America (197)	United Kingdom (103)	Spain (91)	Switzerland (70)
	United States of America (5)	Australia (4)	Japan (1); Ecuador (1); Spain (1); New Zealand (1); Cook Islands (1); Costa Rica (1); France (1); Chile (1); China (1); Fiji (1)		
	Australia (48)	United States of America (15)	Vanuatu (10)	United Kingdom (9)	Fiji (8)
	Australia (17)	Fiji (13)	New Zealand (11)	United States of America (9)	France (3)
	United States of America (3); Japan (3); Australia (3)			Solomon Islands (2); Tonga (2); Cook Islands (2); Iceland (2); New Zealand (2); Kiribati (2); Palau (2); Micronesia (2); Fiji (2); Marshall Islands (2); Papua New Guinea (2); France (2); Niue (2); Vanuatu (2)	
	France (49)	Australia (45)	United States of America (24)	Solomon Islands (10); Japan (10); New Zealand (10)	

Education data

The UNESCO Institute for Statistics compiles education statistics in aggregate form from official administrative sources at the national level. These include data on educational programmes, access, participation, progression, completion, internal efficiency and human and financial resources. These data are collected annually by the UNESCO Institute for Statistics and its partner agencies through the following two major surveys: the education questionnaires by the UNESCO Institute for Statistics and the joint Education Data Collection involving UNESCO, the Organisation for Economic Co–operation and Development (OECD) and Eurostat. These questionnaires can be downloaded from: www.uis.unesco.org/UISQuestionnaires

Innovation data

The UNESCO Institute for Statistics collects data on innovation within the manufacturing industry every two years through its innovation data collection. In addition, the institute obtains innovation data directly from Eurostat and the African Science, Technology and Innovation Indicators (ASTII) Initiative of the African Union/NEPAD Planning and Coordinating Agency for countries which participate in the data collections of these organizations. With a few exceptions, innovation data refer to a three–year reference period that varies from one country to another. The data collected are featured in the institute's international database at: http://data.uis.unesco.org.

Population data

Population data are based on the 2012 revision of the *World Population Prospects* by the United Nations Population Division.

Research and experimental development (R&D) data

The UNESCO Institute for Statistics collects data on resources devoted to research and experimental development (R&D) through its R&D statistics survey. In addition, it obtains data directly from the OECD, Eurostat, the Ibero–American and Inter–American Network on Science and Technology Indicators (RICYT) and the African Science, Technology and Innovation Indicators (ASTII) Initiative of the African Union/NEPAD Planning and Coordinating Agency for countries which participate in the data collections of these organizations.

Data obtained from the OECD are based on the OECD's Research and Development Statistics database released in April 2015. Data obtained from Eurostat are based on the Eurostat Science and Technology database, as of April 2015. Data received from RICYT are as of April 2015. Data obtained from ASTII are based on the *African Innovation Outlook II* (2014) and the *African Innovation Outlook I* (2010). The data collected can be found at: http://data.uis.unesco.org

Cut–off date for data in the Statistical Annex and chapters

R&D and economic data presented in the regional/individual country chapters may not always correspond to the data given in the Statistical Annex or in Chapter 1. The reason for this is that the underlying economic data used to calculate R&D indicators are based on the World Bank's economic data release of April 2015, whereas, in the other chapters, this was based on a previous release of economic data by the World Bank.

TECHNICAL NOTE

Bibliographic data

Number of papers: this is the number of peer–reviewed scientific publications (i.e. articles, reviews and notes only) indexed in the Web of Science database from Thomson Reuters. Publications are assigned to countries according to the field address on the publications. Double counting is avoided at both the national and regional levels. For instance, a paper co–authored by two researchers from Italy and one author from France is counted only once for France and once for Italy but also once for Europe and once for the world.

Number of international collaborations: this is the number of publications involving authors from at least two different countries. For the computation of international collaboration, territories were considered to be part of their respective mainland countries. Thus, collaboration between Guadeloupe and France would not be considered as international co–authorship.

Average of relative citations: this is an indicator of the scientific impact of papers produced by a given entity (e.g. the world, a country, an institution) relative to the world average (i.e. the expected number of citations).

Field classification of publications: a classification from the US National Science Foundation encompassing the 14 following fields of science was used to prepare statistics at the level of scientific disciplines: Agricultural sciences, Astronomy, Biological sciences, Chemistry, Computer sciences, Engineering, Geosciences, Mathematics, Medical sciences, Other life sciences, Physics, Psychology, Social sciences and Unclassified fields.

Education data

Data on internationally mobile students that are collected by the UNESCO Institute for Statistics, OECD and Eurostat encompass students who are pursuing a tertiary degree and thus exclude students on exchange programmes. Data on internationally mobile students reported by host countries are used by the UNESCO Institute for Statistics to estimate the number of outbound students from a given country. Not all host countries specify the country of origin of the internationally mobile students that they host and, thus, the number of outbound students from a given country may be underestimated.

Innovation data

The definitions and classifications used to collect innovation data and produce innovation indicators are based on the third edition of the *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data,* published by the OECD and Eurostat in 2005. The key definitions related to innovation data are presented in the glossary of the present report.

R&D data

The definitions and classifications used to collect R&D data are based on the *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development* (OECD). Some of the key definitions related to R&D data are presented in the glossary of the present report.

Two types of R&D indicator are usually compiled: data on R&D personnel measure researchers, technicians & equivalent staff directly involved in R&D, as well as other support staff; data on R&D expenditure measure the total cost of carrying out the R&D activity concerned, including indirect support.

Regional averages for R&D expenditure and researchers presented in Chapter 1 are derived from imputing numbers for missing data on the basis of calculations done by the UNESCO Institute for Statistics.

Patent data

Number of granted patents: this is the number of granted patents indexed in the PATSTAT database for the US Patent and Trademark Office. Patents are assigned to countries according to the country of the inventors on the applications. Double counting is avoided at both the national and regional levels. For instance, a patent application submitted by two inventors from Italy and one inventor from France is counted only once for France and once for Italy but also once for Europe and once for the world.

UNESCO SCIENCE REPORT

Towards 2030

There are fewer grounds today than in the past to deplore a North-South divide in research and innovation. This is one of the key findings of the *UNESCO Science Report: towards 2030.* A large number of countries are now incorporating science, technology and innovation in their national development agenda, in order to make their economies less reliant on raw materials and more rooted in knowledge. Most research and development (R&D) is taking place in high-income countries, but innovation of some kind is now occurring across the full spectrum of income levels according to the first survey of manufacturing companies in 65 countries conducted by the UNESCO Institute for Statistics and summarized in this report.

For many lower-income countries, sustainable development has become an integral part of their national development plans for the next 10–20 years. Among higher-income countries, a firm commitment to sustainable development is often coupled with the desire to maintain competitiveness in global markets that are increasingly leaning towards 'green' technologies. The quest for clean energy and greater energy efficiency now figures among the research priorities of numerous countries.

Another trend is the growing policy interest in local and indigenous knowledge systems in sub-Saharan Africa and Latin America, in particular.

Gender equality remains a challenge for the future. Despite having achieved parity in higher education in many countries, women are still a minority in research positions worldwide.

Written by more than 50 experts who are each covering the country or region from which they hail, the *UNESCO Science Report: towards 2030* provides more country-level information than ever before. The trends and developments in science, technology and innovation policy and governance between 2009 and mid-2015 described here provide essential baseline information on the concerns and priorities of countries that will orient the implementation and drive the assessment of the 2030 Agenda for Sustainable Development in the years to come.

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